OUTLINES

OF

PHYSIOLOGY,

HUMAN AND COMPARATIVE.

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PREFATORY NOTE TO THE AMERICAN EDITION.

It is no disparagement to the many excellent treatises on Physiology, both at home and abroad, to say that, in some respects, this one is better adapted for general use as a text-book. It is compendious, and yet abounds in all the more recent views and discoveries; and it presents, in connection with Human Physiology, a brief sketch of each function as it appears in the lower orders. In tracing the progress from general to special Physiology, Mr. Marshall has shown himself fully awake to the requirements of the student, and has thus removed one of the great difficulties in the comprehension of the subject.

The additions of the American Editor are comparatively few, and consist, mainly, of such materials as were, perhaps, not easily accessible to the Author, or such as, in the judgment of the Editor, might serve to render the text more intelligible to younger students. These materials have been chiefly drawn from lectures delivered in the University of Pennsylvania, and from experiments. He desires to express his thanks to his friend, Dr. James Tyson, for valuable assistance in preparing the manuscript for the press.

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PREFACE.

The plan of the present work has been designed with the special view to its utility as an Educational Book, the subject being explained, in it, in a particular order and manner, and the Science of Physiology treated as dependent on those of Anatomy, Chemistry, and Physics.

In completing the details of each subject, the best and most recent authorities have been consulted, especially the systematic works of Quain and Sharpey, Gray, Kölliker, Gegenbauer, and Leydig, on Anatomy, and of Carpenter, Todd and Bowman, Müller, and Vierordt, on Physiology. Besides this, many of the articles in Todd's Cyclopædia of Anatomy and Physiology, and many separate works or essays have been referred to, including Papers by Owen, Allen Thomson, Huxley, Beale, and Quatrefages on Anatomical subjects, the Chemical and Physical Essays of Graham, Williamson, Dalton, Helmholz, Playfair, Frankland, Stokes, and Bence Jones, and the Physiological writings of Brown-Séquard, Dubois-Reymond, Bishop, Paget, Savory, Richardson, Lister, and others.

The work, as originally planned, several years since, was of smaller size and humbler pretensions; but as now completed, after considerable labor and in fulfilment of a task once begun, it will, it is hoped, prove serviceable to the student of Medicine and Surgery, presenting a concise but comprehensive summary of modern Physiological Science, both Human and Comparative.

It also offers to all candidates in Natural Science Examinations, to Teachers in Schools where instruction in Physiology is given, and to the lover of Nature generally, a convenient guide, and an ample store of information, in their Physiological studies.

As Anatomy teaches us the Structure of an Organized Body, Organic Chemistry, its Chemical constitution, and Physics, its Physical Properties,—so Physiology instructs us in the Physical, Chemical, and Vital actions which occur in it, during Life. The last-named science therefore requires a certain acquaintance with the others.

The following Outlines of Physiology, accordingly, commence with a short description of the Human Body, its Cavities, and the Organs which they contain. It is then shown how a beginner in Physiological studies may be assisted in this part of the subject by the Dissection of an Animal.

Attention is next drawn to the Textures or Tissues of which the several parts or Organs of the body are composed. The tongue and larynx of the sheep are selected as convenient parts, to illustrate the General characters, Connections, and Uses of these Tissues. The Microscopic Structure of the Tissues in the Human Body is then described; and afterwards, their Physical properties and Chemical constitution.

Under the head of General Physiology, an account is given of the Vital Properties of the Tissues, and a general outline of the Functions of the living Animal Body.

The relations of Man with External Nature are next considered, including a sketch of the Animal Kingdom to which Man belongs, and of the Types and Laws of Form which it presents. To this is added a comparison of the Animal with the Vegetable Kingdom, and of both those Organic Kingdoms with the Inorganic Kingdom.

The Special Physiology of the several Animal Functions is then examined in detail, commencing with those of Animal Life, in the following order:

Animal Motion; Movements generally; Animal Mechanics; Locomotion on solids, in fluids, and in air; Prehension; Manipulation; Gesture; Voice, and Speech.

Sensation, the Regulation of Movement, and the Psychical Functions, or the Functions of the Nervous System. Treated as special subjects under this head, are Sensation generally, and its Modifications; viz., the Internal Sensations, such as Hunger, Thirst, Nausea, and Want of Breath; and the External Sensations, viz., Touch, Temperature, Taste, Smell, Hearing, and Sight.

The foregoing subjects occupy the First Volume.*

The Second Volume is devoted to the functions of Vegetative Life, as follows:†

Digestion, with an account of the Nature and Value of the different kinds of Food.

Absorption, including General Absorption, Absorption of the digested Food, and Interstitial Absorption.

The Circulation of the Blood, its Causes and Phenomena, and the Quantity of Blood in the Body.

Nutrition, both General and Reparative, of the Fluids and Solids of the body, with the Uses of the Blood, and its Vitality, the effects of Hemorrhage, and the phenomenon of the Coagulation of the Blood.

Sanguification, or the processes by which the Blood is renewed. This includes an account of the Uses of the Ductless Glands, together with that of the Liver, considered as a Blood-Gland.

Secretion, or the processes by which certain Glands separate materials from the Blood, for use in the Living Economy.

Excretion, or the processes by which other Glands separate materials from the Blood, to be removed from the Economy.

Respiration, or the Function of Breathing, by which the Blood is purified, and the whole body maintained fit for the performance of all the Functions.

Animal Heat, Light, and Electricity, and their dependence on vita-Chemical action.

Animal Statics and Dynamics, treated of in a separate Section, comprehending an account of the Specific Gravity, the Stature, and the Weight of the body and its Organs; the balance between the Ingesta and the Egesta; the various Forms of Force or Energy exerted in the living body; and the Relations of these Forces to the quantity of Food and Air consumed, and to the Chemical Actions by which such Forces are produced.

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* Ending on p. 479 of the present edition.

† Commencing on p. 480 of the present edition.

The subject of Generation includes a consideration of the different forms of Reproduction in the Animal Kingdom; the Development of the Vertebrate Embryo, its Appendages, Organs, and Tissues, and mode of Reparation of the latter. The Evolution of the Chick is taken as the groundwork of the Description of the Embryo.

This Volume concludes with brief Sections on the Growth of the Body, its Decay and Death.

In treating each Function, the Structure, and, where necessary, the Chemical Composition and Physical Properties of the several Organs, are described; and care is taken to indicate the Mechanical, Physical, and Chemical conditions, in harmony with, and frequently by the co-operation of which they are performed.

At the end of each Section, the General or Essential Characters of a given Function, as distinguished from its Special Characters in Man, are illustrated by copious references to the Structure and Uses of the Organs concerned in that Function in the several Classes of Animals.

The Author desires here to express his deep obligation to Mr. John Castaneda, for much valuable and prolonged assistance.

10 Savile Row,
October, 1867

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OUTLINES OF PHYSIOLOGY.

ANATOMY;

OR,

THE LIFELESS BODY.

THE GENERAL PLAN OF THE BODY.

THE SKELETON.

THE internal solid basis, or framework, of the Human body, like that of the bodies of all the Vertebrate Animals, consists of the *bones*, —which taken together constitute the *skeleton*, Figs. 1 and 2.

The skeleton gives general form to the body, and determines its linear proportions. Like the entire body itself, it is easily subdivided into the Head, the Trunk, and the Limbs. In the natural state, the separate pieces of the skeleton are held together by strong flexible membranous bands, named *ligaments*, as represented on the left side of the figures.

The *head* consists of the smooth round part called the *cranium* or *skull proper*, and of an uneven part corresponding with the *face*,—the bone forming the *lower jaw* being the only movable piece in this portion of the skeleton.

The *trunk* is composed, first and fundamentally, of a strong median column, consisting of many bones, and occupying the middle line of the back, Fig. 2. It bears the head upon its summit, and terminates in the soft parts below. It is called the *back-bone;* also, from its numerous projections backwards, the *spine*, or the *spinal column;* and again, the *vertebral column*, because its numerous component pieces are named *vertebræ*, from *verto*, I turn,—each piece having a slight turning movement upon those next to it. The parts of the spine corresponding with the *neck* and *loins*, have no separate bony pieces attached to them laterally; but in the intermediate part, corresponding with what is generally known as the *back* proper, those long slender curved bones called the *ribs* or *costæ*, are found fastened to it on either side, and passing forwards are prolonged in front by the *rib-cartilages*, the upper seven of which are joined to the *sternum* or *breast-bone* (Fig. 1). Reaching outwards from the top of the breast-bone, on each side to the shoulders, and placed horizontally across the root of the neck, are

Fig. 1.

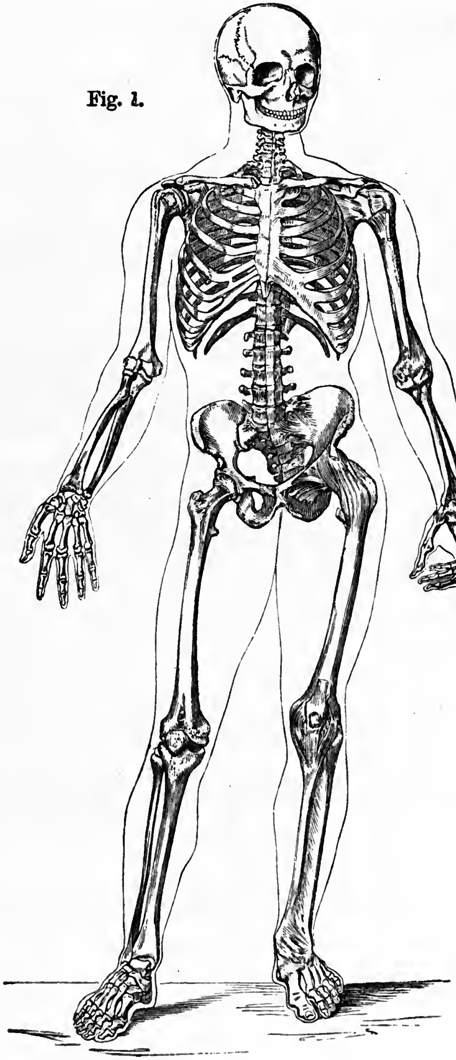

Fig. 1. A front view of the Human Skeleton,—the bones being surrounded with a contour outline, to show their position within the soft parts of the body. The bones of the left side and limbs are represented as if held together by membranous structures at the joints. (*Bourgery and Jacob.*)

the *collar-bones*, so named because a collar worn round the neck rests upon them,—otherwise named the *clavicles*, from the diminutive of *clavis*, a key. To the outer end of each collar-bone, is attached the corresponding *shoulder-bone*, *blade-bone*, *spade-bone* or *scapula* (from *σκαπτω*, *scapto*, I dig). The two flat triangular-shaped *scapulæ*, placed at the back of the trunk, are thus suspended by the collar-bones, so as

Fig. 2.

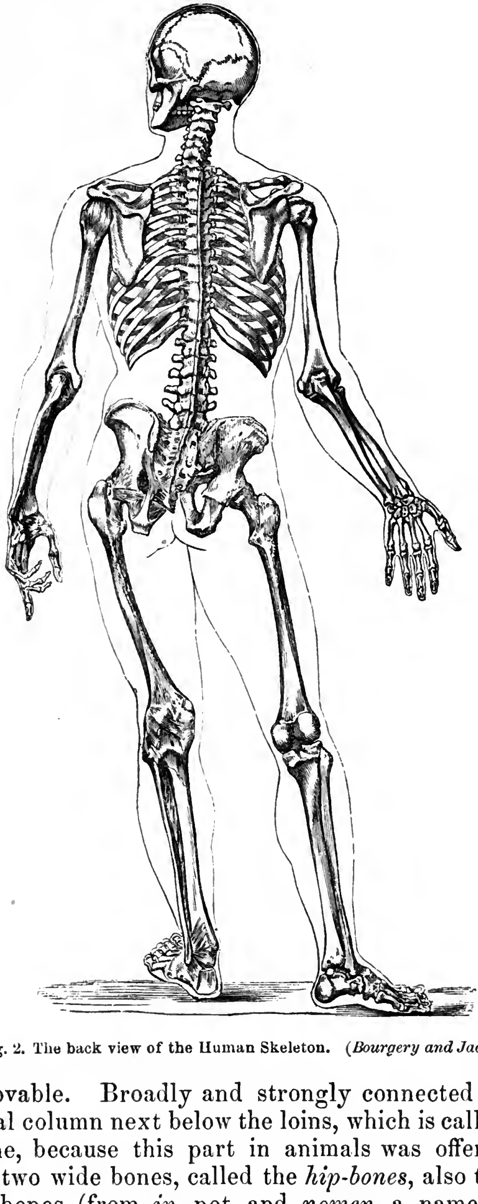

Fig. 2. The back view of the Human Skeleton. (*Bourgery and Jacob.*)

to be very movable. Broadly and strongly connected with the part of the vertebral column next below the loins, which is called the *sacrum*, or sacred bone, because this part in animals was offered in heathen sacrifices, are two wide bones, called the *hip-bones*, also the *innominate* or *un-named* bones (from *in*, not, and *nomen*, a name, because they had no special name). As shown in Fig. 10, each consists of the *ilium*, *i*, the *ischium*, *is*, and the *pubes*, *p*. They are tied firmly together in front, and form, with the intervening sacrum behind, a strong hoop-like base to the trunk, named the *pelvis*, which means a *basin*.

Of the *limbs*,—the upper one, on each side is connected to the comparatively movable scapula, whilst the lower limb is attached to the fixed hip-bone of its own side. The bones of the limbs obviously correspond with those natural subdivisions of arm, fore-arm, wrist, and hand, and thigh, leg, ankle, and foot. The arm-bone is called the *humerus*. Of the two bones of the fore-arm, the outer one, in a line with the thumb, is called the *radius* or *spoke-bone*, and the inner one, in a line with the little finger, the *ulna* or *elbow-bone*, or the *cubit*,—this measure being taken from the distance between the point of the elbow and the tip of the middle finger. The bones of the *wrist* or *carpus* (from *carpo*, I pluck), *eight* in number, are called the *carpal bones;* they are in two rows, viz., the *scaphoid*, *semilunar*, *cuboid*, and *pisiform*, and the *trapezium*, *trapezoid*, *os magnum*, and *unciform bone*. Next to these, are five small long bones, called the *metacarpal bones* (μετα, *meta*, signifying with) which form the base of the thumb, and the broad part of the hand; and lastly, to these, succeed fourteen little bones, *two* for the thumb, and *three* for each finger, named the *phalanges* (from *phalanx*, a row), of the fingers. In the lower limb, the *thigh-bone* is called the *femur*. The inner and larger of the two leg-bones, is named the *tibia* or *shin-bone*, and the outer slender one, the *fibula* or *splint-bone;* the term *tibia* is taken from the resemblance of the bone to an ancient shepherd's pipe, and *fibula* means a *clasp* or *brace*. Succeeding to these bones, are *seven* short ones, named the *tarsal* bones, from *tarsus*, the ankle; the one which is next to the leg-bone, is named the *astragalus;* the large one below this, which projects to form the heel or calcaneum, is named the *os calcis*, or bone of the heel; in front of these, are the *cuboid* bone, on the outer side, and the *scaphoid*, with the three *cuneiform* bones, on the inner side. In front of these are, as in the hand, five bones, one for each toe, called the *metatarsal bones;* and finally to these are attached the fourteen *phalanges* of the toes, of which two only belong to the great toe (as in the thumb), and three to each of the other toes. There is an extra bone in the lower limb, in front of the knee-joint, called the *patella* or *knee-pan;* this, however, belongs properly to the muscular system, as we shall hereafter see. The same may be said of some little rounded bones, found in connection with certain muscles of the thumb and great toe, called *sesamoid* bones, from sesame, a grain of (Indian) corn. At the root of the tongue is the *hyoid* bone.

Whilst contained within the body, all the bones are of course moist; they are also pinkish white, and they are covered with a tough semi-transparent closely adherent membrane, called the *periosteum*. The surfaces of the bones are hard and *compact;* they are marked in places with little holes or pores, which lead into the interior of the bones, where we find, not a solid, but an open spongy-looking or *cancellated* structure, the spaces or cells of which are occupied chiefly by a soft fatty tissue, called the *medulla* or *marrow*.

On looking generally at the bones, it will be seen that to suit various purposes in the body, some of them are *broad* and *flat*, others *short* and thick, and, lastly, others *long* and comparatively slender.

THE JOINTS.

The places where the bones meet, and are joined together by membranes passing from one bone to another, are commonly known as the *joints*,—the connecting membranes being named the *ligaments*, from *ligo*, I tie. The different kinds of joints will be hereafter studied in the Physiological part of this work, in the section on the *Movements* of Man and Animals. In most of them, the ends of the bones are beautifully fitted together, and covered with a thinnish layer of *gristle* or *cartilage*, a tough, elastic substance, smooth on the free surface, and, moreover, moistened with a viscid fluid, improperly termed *joint-oil*, but named *synovia*, from its resemblance to the white of egg (*συν*, *sun*, and *οον*, *oon*, an egg), which is contained in the cavities of the joints, and runs out when these are opened by dividing the ligaments. The interior of the joints, excepting only the cartilages which cover the bones, is lined by a thin membrane, called a *synovial* membrane. These facts are illustrated in the annexed drawing of a section of the right knee-joint, Fig. 3, to the separate description of which reference should now be made.

Fig. 3.

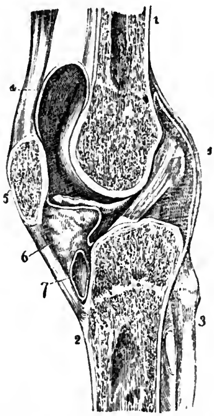

Fig. 3. Vertical section through the middle of the right knee-joint. It shows the cancellated or spongy texture of the lower end of the femur, 1, and upper end of the tibia, 2; also the thin layer of cartilage covering the ends of those bones. 3 is a part of the fibula. 4 is the cavity of the joint, made more apparent by separation of its naturally apposed surfaces, and lined by the synovial membrane. 5, section of the knee-pan, also covered, next the joint, with cartilage. 6, a mass of fat, filling up intermediate space. 7, a separate synovial membrane, called a synovial bursa. 8, one of the ligaments, peculiar to the knee-joint, called the crucial ligaments. (*Bourgery.*)

THE FLESH OR MUSCLES.

Covering up the bones generally, and attached to their surfaces at certain definite places, is the soft, red, fleshy, portion, or *muscular substance* of the body. This consists, not of one homogeneous environing mass, but of a great number (about 400) of distinct fleshy masses of various forms and sizes, which are called the *muscles*, Figs. 4 and 5.

On consulting these figures, it will be seen that on the shape and disposition of the muscles, mainly depend the particular contours of the human body. The muscles will again be noticed, in the Section on the Movements of Man and Animals. In the meantime, it will be observed that they are arranged in *layers*, some *deeper* than others, and lying next to the bones, as seen in the left half of the trunk in Fig. 4, and some more *superficial*, as shown on the right side of the trunk. It will be noticed that, on the trunk, the muscles are generally *broad*, and, on the limbs, *longer*, and *narrower*. Many of the muscles are connected with the bones *directly*, by broad surfaces; but many are attached *indirectly*, by means of glistening *white* structures called

Fig. 4. A dissected view of the principal muscles of the Human body. On the left half of the trunk, the muscles which lie next upon the bones, are shown. On the right half, the superficial ones are represented In the head, neck, and limbs, no muscles are removed. The narrow white cords connected with the muscles, are the tendons. (*Bourgery and Jacob.*)

tendons, which may be broad, short, and flat, as on the trunk, or long, narrow, and cord-like, as in the limbs. All the muscles of the body are held together by an intermediate moist and whitish, web-like structure, called *intermuscular areolar* tissue; sometimes a firmer membrane separates them, forming *intermuscular septa;* and most of them, especially those of the limbs, are bound down by a general membranous investment, called the *fascia* (Fig. 5, on the left limbs), which

Fig. 5.

Fig. 5. A dissected view of the muscles found on the back of the Human body, and on the posterior aspect of the limbs. In the case of the left limbs, the membranous expansion called the fascia, which immediately invests the muscles, is supposed to remain upon them; whilst in the right limbs it is removed. (*Bourgery and Jacob.*)

is thicker on the outer aspect of the limbs, and especially in the palms and in the soles, than elsewhere. This fascia is also shown in Fig. 6.

THE INTEGUMENTS.

Outside the fascia, but connected with it, is a layer, or two, of loose web-like *areolar* tissue, containing in its meshes more or less fat; and outside this, again, and connected with it, is the *integument* or *skin*,

Fig. 6.

Fig. 7.

Fig. 6. A superficial dissected view of the left arm—the skin, and subcutaneous fat and areolar tissue having been removed. It shows the fascia, or membrane, which invests the muscles and their tendons; it also displays the superficial, or subcutaneous, veins 1, 1—and nerves,—the former being shaded, and the latter left as white cords. (*After Bourgery.*)

Fig. 7. A deep dissected view of the left upper limb,—the fascia having been removed, and some of the muscles taken away, so as to show the main arteries of the limb (here shaded with cross lines), 1, and the deep-seated nerves (left as white cords), 2, 3, 4. (*After Quain.*)

which is thus held down to the fascia. The areolar tissue and the fat are both called *subcutaneous* (*sub*, under, *cutis*, the skin). Together with the skin itself, they round off, fill up, and finish the contours of the whole surface of the body.

THE VESSELS AND NERVES.

Coursing along in the subcutaneous areolar tissue, and therefore just beneath the skin, are certain delicate tubes and cords called the *superficial vessels* and *nerves*, which in the limbs are found resting upon or outside the fascia, Fig. 6. The vessels are of two kinds: first, the *bloodvessels*, which convey the *blood*, namely, the *arteries*, not here represented, being comparatively small, and the *veins*, which are larger, and are shown as dark meandering lines; and, secondly, there are the *absorbent vessels*, which convey a thin colorless fluid called *lymph*, and which are exceedingly delicate, and can only be demonstrated by consummate skill and the aid of mercurial injections: these absorbents have little bodies connected with them at the bendings of the great joints called the *absorbent glands*. The superficial nerves are delicate white cords, shown in the figure as white lines; they are the *cutaneous nerves*, which perforate the fascia to reach the skin.

When the fascia is removed, and the muscles dissected out, and some of them cut away, the *deep bloodvessels* and *nerves* are brought into view, taking their course in the intervals between the muscles. They are connected by branches perforating the fascia with the superficial sets. In Fig. 7, the main *arteries* of the upper limb are shown; the *veins* are omitted for the sake of clearness; the deep nerves, or *muscular nerves*, belonging to the muscles, are exhibited; the *deep absorbents* are so delicate as to be quite undemonstrable in so small a figure.

Such, then, are the parts to be found in the limbs, proceeding from within outwards, viz., the bones containing their marrow, and covered with the membranous periosteum; the cartilages, ligaments, synovial membranes, and synovia of the joints; the muscles with their tendons; the intermuscular septa and areolar tissue, in which the deep absorbents, bloodvessels, and nerves are found proceeding to and from the muscles, bones, and joints; the fascia investing the muscles; the subcutaneous areolar tissue and fat, containing the superficial bloodvessels, absorbents, and nerves belonging to the skin; and, lastly, the skin itself.

The very same parts are also found in the head, and in the general framework of the trunk. But in these situations the skeleton not only constitutes a central axis or basis for the surrounding muscles and other soft parts, but some of its pieces are so shaped, arranged, and held together as to inclose certain spaces or hollows, called the *cavities* of the body, in which those special parts of the system, called the *Organs* or *Viscera*, are lodged and protected.

THE CAVITIES OF THE BODY AND THEIR CONTAINED ORGANS.

Three great Cavities are formed in the framework of the body, viz., those of the Skull, the Chest, and the Abdomen. There is also a subordinate cavity within the spinal column, and several others in the face.

Fig. 8.

Fig. 8. The bones of the head, which consists of the cranium, and face; 1, frontal bone; 2, left parietal bone; 3, left temporal bone; 4, right upper jawbone; 5, lower jawbone; 6, right cheek-bone. This figure also shows the two eye-sockets or orbits, the opening leading into the right and left nasal or nose-cavities, and the arrangement of the teeth in the jawbones. The cranium has eight, and the face fourteen bones. (*From Nature.*)

a. The cavity of the skull, shown cut through vertically in the middle line in Fig. 9, has completely solid walls, formed of the united bones of the cranium. One of these bones, the *frontal*, Fig. 8, 1, corresponds with the forepart of the head (the *frons*, forehead), and also forms the upper margin of the sockets for the eyes; two others, one on each side, 2, called the *parietal* bones (*paries*, the side), form the sides and top of the skull; other two, also existing in pairs, called the temporal bones, 3, correspond with the temples (*tempus*, time); another single bone, which forms the back of the head, is called the *occipital* bone (*ob* and *caput*, the head); and two other single bones, viz., the *sphenoid* or wedge-shaped bone, and the *ethmoid* or sieve-like bone, complete the base or floor of the skull, which is also in part composed of the occipital and temporals. All these bones are joined together by their edges, which are unevenly toothed, or serrated, so that the lines by which they meet, called the *sutures* of the skull, are more or less uneven or zigzag. It is also obvious that the walls of the skull are put together after the manner of an arch or vault. The cavity of the skull is lined throughout by a tough membrane, called the *dura mater*, Fig. 9 *c* (hard mother), which acts as a sort of internal periosteum, and also smooths off the asperities of the bony surface. The dura mater also sends off a vertical partition downwards along the middle line, named, from its *sickle*-shape, the *falx*, *f*, which again falls behind on a transverse partition, called the *tentorium* or *tent.* The interior of the dura mater is everywhere lined by a very thin, smooth, and moist membrane, belonging to the *serous membranes*, and named the *arachnoid* (αραχνη, *arachne*, a spider). From the back part of the base of the skull there extends nearly the whole length down the centre of the spine or back-bone, a secondary cavity, or rather a long canal, which is called the *spinal* or *vertebral canal.* The upper part of this canal, *s*, and its continuity with the cavity of the skull, which is effected through a large hole in the occipital bone, called the occipital *foramen* (or hole), are clearly seen in Fig. 9. It is lined by a tubular extension of the dura mater, covered on its inner surface with the arachnoid membrane: the dura mater does *not* here attach itself closely to the bones, which have their proper periosteum distinct from it. The mode in which the bony canal is formed is this. The spine, as already stated, consists of a series of bones called vertebræ, arranged in form of a column. There are in the *neck* (cervix), Fig. 10, 1, *seven* of these bones, called *cervical ver-*

tebræ; in the *back* (dorsum), 2, *twelve dorsal vertebræ*, from * to *; in the *loins* (lumbi), 3, *five* lumbar vertebræ; making in all twenty-four *movable* vertebræ. Next below these are five *sacral* vertebræ, consolidated into the one mass called the sacrum, 4; and below this are three or four little bones, called the *coccygeal* vertebræ, 5, forming the *coccyx* (cuckoo's bill): these constitute the *immovable* vertebræ. It should also be here stated that the bones of the head are considered as consisting of specially modified bony elements, called *cranial* vertebræ. Each of the vertebræ, as shown in Fig. 11, in which *a*, *c*, and *e*, represent the right side, and *b*, *d*, and *f*, the upper surface of a

Fig. 9.

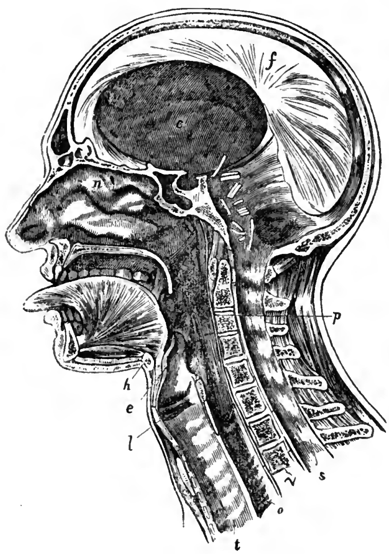

Fig. 9. A section vertically through the middle of the head and neck. The hollow of the skull, lined by the membranes called the dura mater and the arachnoid, is marked *c*. The membranous partition, called the falx, is marked *f;* its hinder part being connected below with the right half of the tentorium. The spinal canal, *s*, leading from the cranial cavity, is seen lower down still. The cut ends of certain cranial nerves are also shown. Along the upper edge of the falx, close to the bone, is a large channel or venous sinus. The sections of the cranial, facial, and spinal bones are also seen. The right nasal cavity is marked *n*. Below it is the cavity of the mouth, containing the tongue; these two cavities are separated by the hard and soft palate. Both of them open behind into the throat cavity or pharynx, *p*, which again leads downwards into the gullet or œsophagus, *o*, immediately in front of the spine. At the root of the tongue is seen the cut surface, *h*, of the hyoid or lingual bone; suspended to this is the larynx, *l*, the hollow cartilaginous organ in which the voice is produced, and through which the air passes from the pharynx into the windpipe, *t*, which is the open tube running down the front of the neck from the larynx. The divided bodies of the vertebræ are marked *v*. (*After Bourgery.*)

characteristic cervical, dorsal, and lumbar vertebra, consists of a solid part called the *body*, which is turned forwards, and which is strongly tied to the bodies of the adjacent vertebræ; secondly, of an open *ring* behind this; and thirdly, of three principal projections or processes, one backwards, called the *spinous process*, from the whole series of which the backbone is called the spine, and two lateral ones called the *transverse* processes; there are also four other shorter processes on each movable vertebra, two above and two below, called the *articular* processes (*articulum*, a little joint), by which the several bones are still further joined together. The only part which now concerns us is

Fig. 10.

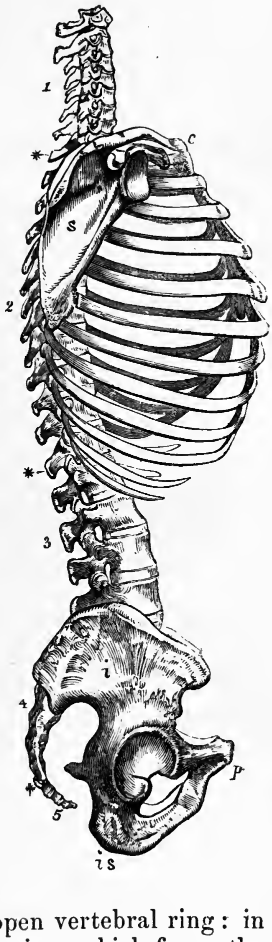

Fig. 10. Right side of the bones of the trunk. 1 to 5 is the spinal column; 1, the cervix or neck, consisting of seven cervical vertebræ. 2, from * to *, the dorsum or back, consisting of twelve dorsal vertebræ; 3, the loins, consisting of five lumbar vertebræ; 4, the sacrum, composed of five consolidated sacral vertebræ; and 5, the three or four imperfect vertebræ called coccygeal. The twelve ribs of the right side are also seen; and the inner side of the sternum in front. The right collar-bone is marked *c*; the right scapula *s*. The right hip-bone, or innominate bone, is indicated by three letters: *i* on the part called the ilium, *is* on the ischium, and *p* on the pubes. The large rounded deep hollow cup where these three parts meet, is the acetabulum or socket for the head of the thigh-bone; it contrasts with the small, oval, shallow depression in the scapula, named the glenoid cavity, intended for the reception of the humerus (*From Nature.*)

the open vertebral ring: in the natural state it is the succession of these rings which forms the spinal canal, Fig. 12, *c*, *e*.

Now, the cavity of the skull contains the large, soft, pulpy organ called the *brain*, which is itself composed of the *cerebrum*, or *brain proper*, Fig. 12, *a*, and the *cerebellum*, or *little brain*, *b*. The cerebrum and cerebellum are connected together at the under part or *base of the brain;* but, above, the cerebrum is parted into two lateral halves or *hemispheres*, which are lodged one on each side of the falx, whilst, below, the tentorium separates the cerebrum from the cerebellum. The mechanical support thus afforded by the tentorium and the falx is obvious enough. From the base of the brain there is sent down a thick, white, stalk-like prolongation into the spinal canal, which is named the *spinal cord*, *c*. It extends down only to the first lumbar vertebræ, *c′*. The brain and spinal cord are the *great centres* of the nervous system. From the base of the former, and from the sides of the latter

Fig. 11.

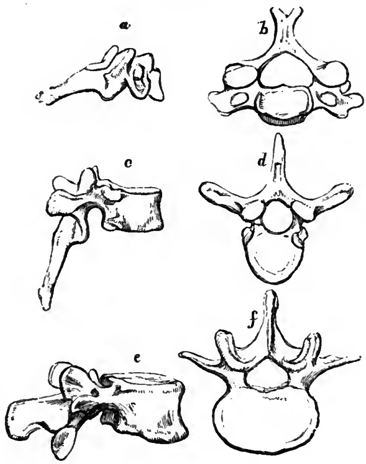

Fig. 11. Two different views of a characteristic cervical, a dorsal, and a lumbar vertebra. *a*, right side, and *b*, upper surface of a middle cervical vertebra; *c* and *d*, similar aspects of a middle dorsal vertebra; and *e* and *f*, the same of a middle lumbar vertebra. These figures show the thick or anterior part or body of the bones, their rings, their backward or spinous processes, their lateral or transverse processes, and their articular processes. The differences in size and form between each of these parts in the different vertebræ are also shown. (*From Nature.*)

(see Fig. 62), are given off the white cords, called *nerves*, which, passing through special openings in the base of the skull (see the cut ends of several in Fig. 9), or through the *intervertebral* apertures between the vertebræ (see Fig. 10, especially in the loins), branch out into every part of the body—(see Fig. 64). The nerves form the *peripheral* part of the nervous system. The brain and spinal cord are closely invested by a vascular membrane, the *pia mater*, over which is a layer of the arachnoid continuous along the roots of the nerves with that lining the dura mater.

The part of the entire skull which we call the face also has certain hollows or recesses in it, which may be regarded here as *cavities* for the lodgment of organs. Of the bones which are consolidated together below the cranium to form the face, some are seen on the surface, viz., the *cheek*-bones, Fig. 8, 6, or *malar* bones (*malæ*, the cheeks), which assist in forming the margins of the eye-sockets; the two upper jaw-bones, 4, or *superior maxillary* bones (*maxillæ*, the jaws), which, together, contain the upper teeth, form the sides of a great notch which corresponds with the nose, and also ascend to complete the margins of the eye-sockets; the two little *nasal* bones (*nas*, the nose), which complete the upper boundary of the nasal cavities, and form the bridge of the nose; and, lastly, the lower jaw-bone, or *inferior maxil-*

Fig. 12.

Fig. 12. A vertical median section through the cavity of the skull, and the spinal canal, to show the way in which the brain and its prolongation, the spinal cord, are lodged within the bony axis of the body. *a* is the cerebrum, or brain proper; *b* the cerebellum, or little brain; *c* the spinal canal; *c′* the lower end of the spinal cord; *e* the roots of the lumbar or sacral nerves, forming the cauda equina, or so-called horse's-tail; *s* the sacral plexus of nerves, and *n* the great sciatic nerve. This cut also shows sections of the bodies and rings of all the vertebræ; and of the nose, mouth, throat, gullet, tongue, larynx, and windpipe. The brain and spinal cord are protected from the bones by the dura mater, by two layers of the arachnoid, and by the inner membrane or pia mater. (*After Bourgery.*)

lary bone, 5, a single strong bone, shaped like a horseshoe with its ends turned up, which finishes the face below, and gives form to the chin. Other bones, such as two *palate* bones, which complete the hard palate, the *vomer* or *ploughshare* bone, the edge of which is seen in Fig. 9, and which helps to part off the right from the left cavity of the nose, two twisted or *turbinated* bones within the nose, and the two little *lacrymal* bones in the orbits, also enter into the formation of the face. Like the cranial bones, those of the face, of course excepting the lower jaw, are joined by sutures, but the lines of suture are more even than in the cranium.

The cavities of the face are these: first, the two *eye-sockets* or *orbits*, for the lodgment of the eyeballs, their muscles, vessels, and nerves, and of two little bodies called glands, which secrete or form the tears,—the *lacrymal glands* (*lacrymæ*, the tears); secondly, the *nasal cavities*, right and left, separated one from the other by a median partition, partly bony and partly cartilaginous, and from the mouth by the palate, but opening backwards (as shown in the perfect state of the parts in Fig. 9, in which *n* indicates the right nasal cavity) into the upper part of the throat-cavity or pharynx, *p*, as well as forwards through the nostrils; thirdly, the cavity of the *mouth*, which also communicates with the pharynx, *p*, through the arched opening named the *fauces*, where the *tonsils* are seen at either side and the *uvula* in the middle; it contains, besides the tongue and teeth, two of the glands, named *sublingual* (*sub*, under, and *lingua*, the tongue), which secrete or form the saliva; lastly, there are certain small chambers, situated within the temporal bones, and communicating, at least in the dried state, with the exterior of the sides of the head, in which the apparatus of the internal ears is contained. We see, then, that the hollows of the face contain the various organs of the senses.

On the sides of the face and neck, behind and below the lower jaw, are four more salivary glands, two on each side, the *parotid* and *submaxillary* (see Fig. 14), certain ducts or tubes from which convey the saliva which they secrete into the mouth.

In the *neck*, which is interposed between the head and the chest, there is no regularly defined and protected cavity, but certain important parts are found there, passing downwards from the pharynx, to reach the chest. Immediately beneath the root of the tongue, just at the re-entering angle of the neck, is situated the little *lingual* or *hyoid*, *i. e.*, υ-shaped bone (shown in section at *h*, Fig. 9), which helps to support the tongue. Suspended to this hyoid bone, is a hollow cartilaginous organ, corresponding with the prominence of the throat, called the *larynx*, *l*. This is the organ of the voice; it communicates above with the pharynx, by means of a slit-like aperture, called the *glottis*, which is protected by a flap or valve, named the epiglottis, *e;* below, the larynx opens freely into the *windpipe* or *trachea*, which passes down into the chest, Fig. 15, *t*, to branch into the lungs, and is known by the numerous cartilaginous rings, which enter into its construction, and keep it constantly open. Behind the larynx, the pharynx, *p*, becomes continuous with a membranous tube, called the *gullet* or *œsophagus*, Fig. 15, *o*, which also passes down behind the wind-pipe, and in front of the bodies of the cervical vertebræ into the chest, and thence on into the abdomen, to end in the stomach, as we shall presently see.

b. The *chest* or *thorax* is not, like the cranium, a complete osseous box, but rather an open cage-work of bones, consisting of the dorsal part of the spine, the twenty-four ribs, and the sternum, Fig. 10, the intervals between which are occupied with muscles, membranes, vessels, and other soft parts. It therefore admits of certain essential alterations of its size. The thorax is conical in form, being narrowest above, where it is closed chiefly by the tubes and vessels passing into or out of it from or to the neck, and widest below, where it is separated from the other large cavity of the trunk,—the abdomen,—by a vaulted partition, partly muscular and partly tendinous, called the *diaphragm*, Fig. 14, *d*, which springs from the spine, and is inserted into the lower borders of the cartilages of the seventh and the succeeding ribs, and into the tip of the sternum, all of which parts are represented as being preserved in Fig. 13, to show the boundary between the opened chest and abdomen. The interior of the thorax is divided by membranes into three compartments: thus, on each side is a large compartment marked off and lined throughout by a thin, continuous, and moist *serous membrane*, called the *pleura*, which forms a completely closed sac, so that there are two *pleuræ*, or two distinct pleural sacs, one right and the other left. The right *lung* occupies the right pleural sac, and the left *lung* the left pleural sac, as may be seen in the annexed drawing, Fig. 13. The cut edge of the right pleura is distinctly seen on the inner side of the right lung. The lungs, *l l*, are attached only at their roots, which are found at their posterior borders; everywhere else they are covered with a layer of their corresponding pleura, which is reflected upon them at their roots, so that each lung is really *outside* the sac of its pleura, the moist inner surfaces of which touch each other,—the lungs everywhere filling up their own compartments of the thorax. In the root of each lung is found a branch of the windpipe, certain large bloodvessels, other smaller ones, with absorbents and nerves.

Between the two pleural sacs is a space called the *mediastinum*, in

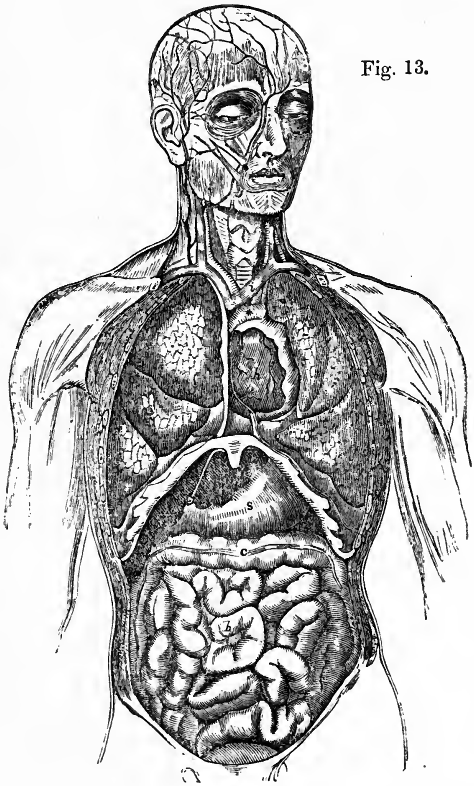

Fig. 13.

Fig. 13. Front view of the cavities of the thorax and abdomen, laid open by removal of their anterior walls. The tip of the sternum, and part of the cartilages of the seventh and following ribs, are preserved, as the diaphragm which separates these two large cavities of the trunk is fixed to them. In the thorax are seen the right and left lungs, *l l*, occupying each its own compartment; and between them the pericardium, or bag of the heart, laid open to show a part of that organ, *h*. Passing up from the heart to the sides of the neck are the great bloodvessels, the aorta *, the vein *i*, between which are seen the windpipe, larynx, and pharynx. Below the diaphragm, and therefore in the abdomen, is seen, projecting below the right ribs, a part of the liver, *a*, crossed by a white line, which is the cut edge of its broad ligament: from a notch low down projects the gall bladder. Under the liver, and to the left is the stomach, *s*, at the left end of which is seen a piece of the spleen; below it is the transverse part of the great intestine, or transverse colon, *c*, ending on the right side below the liver, in the ascending colon, and on the left in the descending colon. Occupying the middle of the abdomen are the coils or convolutions of the small intestines. Lowest of all is the top of the urinary bladder. (*After Bourgery.*)

which many parts are found. The chief of these is the *heart*, Figs. 13 and 14 *h*. This organ is inclosed in a distinct fibrous bag or sac, lined by a smooth moist serous membrane, and named the *pericardium*, the forepart of which is cut away in Fig. 13, to show a portion of the heart, *h*. The heart, as seen in Fig. 14 (in which both lungs are taken

Fig. 14.

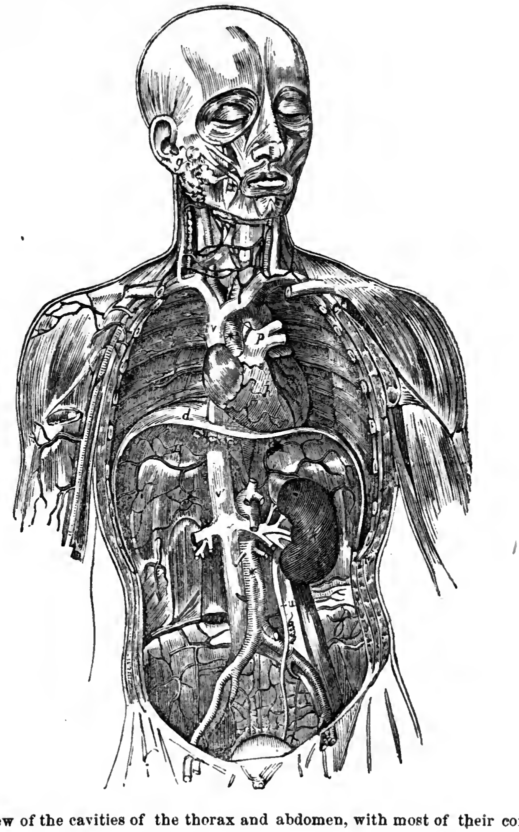

Fig. 14. Deeper view of the cavities of the thorax and abdomen, with most of their contents removed. In this figure the anterior half of the diaphragm is cut away. From the thorax, the lungs are removed; the pericardium is also dissected away from the heart, *h*, which is left attached to the great bloodvessels, of which *p* represents the pulmonary artery, * the aorta, and *v* the superior vena cava. The inferior vena cava, which is seen perforating the diaphragm, *d*, to reach the heart, is marked *v′*. The abdominal aorta is also marked with an asterisk *. The left kidney, *k*, is seen in its natural position, with its arteries and veins going into and out of it, also with its ureter or duct, *u*, leading down to the urinary bladder, which lies almost entirely concealed in the pelvis. The left supra-renal body surmounts the kidney. (*After Bourgery.*)

away), is attached above by the tubes or *great bloodvessels*, which spring from it, and branch out into all parts of the body. Of these vessels there are two kinds, as already mentioned in describing the bloodvessels of the limbs, viz., *arteries* and *veins*. The great artery, *p*, whose branches are distributed to the lungs, is called the *pulmonary artery* (*pulmo*, the lung); the *pulmonary veins*, which proceed from the lungs to the heart, enter that organ behind, and are not seen in this figure. The asterisk * is placed on the *aorta*, the great arterial stem, from which all the arteries of the body are given off: their branches in the neck and elsewhere may be known by their being shaded with cross lines: the continuation of the aorta in the abdomen below the diaphragm, *d*, is also marked with an asterisk *. The great venous trunks, in which the veins of the body ultimately end, are marked *v*, which indicates the *superior vena cava*, receiving the veins of the head, neck, chest-walls, and upper limbs, and *v*, placed on the *inferior vena cava*, receiving the veins from the lower half of the trunk, and from the lower limbs, and seen perforating the diaphragm *d*, to enter the heart. Thus attached, at its base only, by the above-named great bloodvessels, the heart projects forwards and to the left side, so that its point or apex comes near the walls of the chest, between the fifth and sixth ribs, a little to the left of the sternum. The sac of the pericardium, below, adheres to the diaphragm ; at the base of the heart its fibrous layer adheres to the great bloodvessels, but its lining membrane or serous layer is reflected upon them, over the surface of the heart, so that this organ, like the lungs, is outside its serous sac, like a man's head thrust into an old-fashioned double nightcap.

When the heart is removed, as in Fig. 15, it is seen that besides the aorta, *a*, the thorax also contains the lower end of the trachea, or windpipe, *t*, which divides therein into two chief branches, called the *bronchi*, which ultimately ramify throughout the lungs, forming its innumerable *air-tubes* or *bronchial tubes* (see Fig. 111). The thorax also contains the longest portion of the *gullet* or *œsophagus*, *o*, which is seen descending from the pharynx, *p*, supported all along upon the bodies of the vertebræ, and which perforates the diaphragm to enter the abdomen behind the liver, *l l′*, and end in the stomach, *s*. Besides these parts, there are found in the thorax, the principal *absorbent vessel* in the whole body, or main trunk of those vessels, called the *thoracic duct*, which, as shown in Fig. 100, runs up through the thorax, from the abdomen into the neck, resting closely on the vertebral column. Lastly, the thorax also contains portions of the *sympathetic nerves*, and their branches. These, as shown hereafter in Fig. 64, form a knotted cord on each side of the vertebral column.

But the chief contents of the thorax are the heart and lungs, the great central organs of circulation and respiration.

c. The *cavity of the abdomen* is even less protected by bones than that of the chest, being surrounded by soft parts only, such as broad muscles, tendons, fascia, and skin, excepting behind, where there is the lumbar portion of the spine, and below, where we find the pelvis, the cavity of which may be regarded here as supplementary to, as it is directly continuous with, the abdominal space. Above, the abdomen is as it were roofed in by the vaulted diaphragm, Fig. 14, *d*. The capacity of the abdomen, as is needed for its contained organs, may vary very much.

Deeply seated in the abdomen are the great bloodvessels already mentioned, viz., the *abdominal aorta*,* and the *inferior vena cava*, *v′*, both giving off, of course, their numerous branches. Quite at the back of this cavity, corresponding with the region of the loins, on each side of the spine, are the two *kidneys*, of which the left one, seen in

Fig. 14, *k*, is placed rather higher than the other: from the inner border of each kidney descends a slender tube *u*, called the *ureter*, which

Fig. 15.

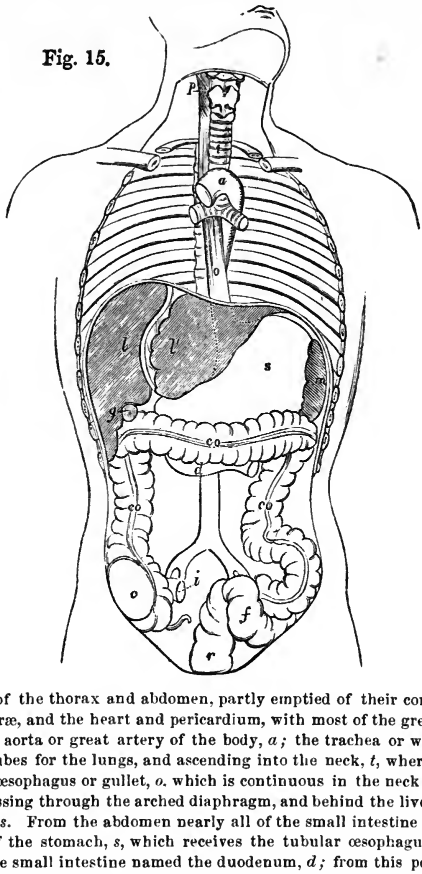

Fig. 15. The cavities of the thorax and abdomen, partly emptied of their contents. From the thorax the lungs and their pleuræ, and the heart and pericardium, with most of the great bloodvessels, are taken away: there remain, the aorta or great artery of the body, *a*; the trachea or windpipe, branching below into the bronchi or air-tubes for the lungs, and ascending into the neck, *t*, where it is surmounted by the larynx; and lastly, the œsophagus or gullet, *o*. which is continuous in the neck with the pharynx, *p*, and in the abdomen, after passing through the arched diaphragm, and behind the liver, as shown by the dotted lines, with the stomach, *s*. From the abdomen nearly all of the small intestine has been removed. There is seen the dilated bag of the stomach, *s*, which receives the tubular œsophagus above, and opens below into the upper part of the small intestine named the duodenum, *d*; from this point to the short piece of the lower part of the small intestine named the ileum, marked *i*, the intestine is taken away. The commencement of the large intestine, called the cœcum, c, with its little appendix, is lodged above the right groin. Then follows the ascending, transverse, and descending colon, *co*, *co*, *co*; next the sigmoid flexure of the colon, *f*, and lastly the terminal part of the alimentary canal, named the rectum, *r*. In the middle line is seen the abdominal aorta, and its terminal branches. The two lobes of the liver are marked *l l'*; between them is part of its broad ligament; *g*, is the gall-bladder; *m*, the spleen. (*A Plan.*)

descends into the pelvic cavity, and there opens into the *bladder:* at the top of each kidney is the *supra-renal body.* In front of the bloodvessels and kidneys are found the essential organs of digestion, which indeed occupy nearly the whole abdomen. These consist, first, of the long membranous tube, constituting the abdominal portion of the *alimentary canal*, and, secondly, of certain accessory organs called *glands*.

When the anterior part of the walls of the abdomen is cut away, as in Fig. 13, there is seen a small portion only of the large, dark red, firm glandular organ, called the *liver*, *a*, with the end of its little attached bag, named the *gall-bladder*, projecting from a notch in its lower border; there also comes into view the larger portion of the anterior surface of a dilated part of the alimentary canal called the *stomach*, *s*, and certain portions of the rest of the alimentary canal, namely, most of the coiled foldings or *convolutions* of the *small intestine*, *b*, surrounded on three sides by a part of the *great intestine*, *c*. Supposing the thorax to be emptied, and the anterior half of the diaphragm to be cut away, as in Fig. 15, then the liver, *l l′*, is seen occupying the right upper part of the abdomen, close to, and even suspended from, the under surface of the diaphragm; the end of the gall-bladder, *g*, is here also plainly visible. Partly covered by the liver, as shown by the dotted lines, is the stomach, *s*, with the lower end of the gullet, *o*, opening into it above; at the left end of the stomach, and attached to it, is a dark, purplish organ, *m*, named the *milt* or *spleen*. To the right, the stomach, or dilated part of the alimentary canal, curves downwards behind the transverse part of the great intestine, *co*, and opens into the commencement of the small intestine, named the *duodenum*, *d;* the succeeding part of the small intestine, named the *jejunum*, is here removed, and so is the lower part named the *ileum*, except a short piece marked *i;* this part opens into the commencement of the large intestine, which is named the *cœcum*, *c*, from which a little worm-like tube, called the *vermiform appendix*, proceeds. The cœcum is continuous with the next part of the large intestine, called the *colon*, which consists of four portions, named from their directions, the *ascending*, *transverse*, and *descending* colons, *co*, *co*, *co*, and the *sigmoid*, that is the *S-shaped flexure*, *f*, of the colon. The remainder of the large intestine, *r*, the terminal portion of the alimentary canal, is named the *rectum*, from its comparatively straight course. If the liver, stomach, duodenum, and spleen be removed together from their position in the abdomen, as in Fig. 98, and if the liver, *l*, and stomach, *s*, be then turned up, so as better to show the duodenum, *d*, there will then be seen stretching across from the curve of the duodenum on the right, to the spleen, *m*, on the left, a long pinkish-white gland, very like a salivary gland, named the *pancreas*, *b*. It is further shown in this figure that the liver and pancreas are provided with ducts, which open into the duodenum. The spleen has no duct; neither have the supra-renal bodies. In Fig. 15 the pancreas is concealed by the transverse colon and stomach.

Besides the various above-named parts and their proper bloodvessels, there also exist in the abdomen very numerous *absorbents*. Those belonging to the small intestine, named the *lacteals*, serve, as we shall hereafter see, a very special office, and empty themselves into the commencement of the *thoracic duct*, which begins in the abdomen (see Fig. 100). It remains to notice that the lower portions of the right and left *sympathetic nerves*, and their branches to the neighboring viscera, are likewise contained in the abdominal and pelvic cavities.

There are no special or separate compartments in the abdominal cavity, as there are in the thorax; but the whole is lined by a single smooth, serous membrane, called the *peritonæum*. This membrane is also reflected on the stomach and intestines, reaching them from behind, along their bloodvessels, and serving to support them by folds called *mesenteries.* A large apron-like fold of the peritonæum, containing much fat, and named the *great omentum*, also hangs down from the stomach and transverse colon, over the small intestines, and doubtless serves to protect them and preserve their temperature: it is not shown in any of our figures. The peritonæum is also reflected on to the spleen and likewise from the diaphragm over a great part of the liver, assisting to support it and to form its so-called *ligaments;* but the pancreas, and the kidneys and supra-renal bodies are altogether behind it.

DISSECTION OF AN ANIMAL.

There are many respects in which the preceding outline of the general plan of construction of the human body will be better understood, if the student at this stage procure and dissect the body of a dog or rabbit. The latter being more easily obtained is described here. Due allowance must of course be made for differences, not only in the size, but also in the form, color, and strength of construction of the parts of the animal as compared with the human organs. The student will find the following course of dissection the most convenient and useful:

Place the dead animal on its back, secure the legs, and then divide the skin only along a line reaching from beneath the chin to the lower part of the abdomen. In now reflecting the *skin*, by dissection, from the subjacent parts, the loose *subcutaneous areolar tissue*, containing in its areolæ or meshes more or less fat or *adipose tissue*, will be met with, and cut across. When the skin is reflected, say from off the right half of the body, the soft pinkish flesh will be visible through the thin, firm, fibrous membrane called the *fascia;* which will be found easier to display on the limbs than elsewhere. The fascia being now removed by another step in the dissection (taking care that the knife be made to follow the direction of the fleshy bundles which are being exposed), the flesh itself, or muscular substance, is seen to be collected into masses, forming the so-called *muscles*, and separated from one another by loose areolar tissue, or by firmer membranes, called *intermuscular septa.* The muscles of the thigh and leg will be found the easiest to dissect. Some muscles will be seen to have direct and broad attachments to the skeleton, and others to be indirectly connected to the bones by either broad, or long and slender, whitish, inextensible cords called *tendons.* The latter are principally found in the limbs; one of the most remarkable being placed at the back of the leg, and connecting the muscles of the calf with the heelbone. In dissecting the muscles on the inner side of the thigh, the large bloodvessels proceeding out of the abdomen will be met with,—being known, the *vein*, by its being a flaccid tube containing *blood*, and the *artery* by its remaining open or gaping, if cut across. Near these vessels, some slender white cords, which are *nerves*, may be detected; but the chief nerve of the thigh will be found at the back of that part of the lower limb, descending amongst the muscles into the ham, or space at the back of the knee. *Absorbent vessels* also exist, but they are much too minute and delicate to be detected except by the most expert anatomist using very special means of research; the *absorbent glands* will probably also be overlooked, in the fat and cellular tissue of the groin. The muscles and their tendons being now cleanly cut away from the side of the pelvis, and from the thigh and leg, the exposed *bones* are seen to be whitish, moist, though hard structures, covered closely with a tough membrane, the *periosteum*, portions of which may be dissected or stripped off. The *joints* of the thigh and knee may now be cleaned externally; and their *ligaments*, the fibrous bands which tie the respective bones together, may be examined. On cutting through the latter, the closed sacs, or cavities of the joints, will be opened, showing the articular ends of the bones, nicely modelled so as to fit together, and covered with closely adherent and beautifully smooth *cartilage*, the whole moistened with the viscid fluid, *synovia*, secreted from a thin *synovial* membrane which covers the interior of the joint, excepting the cartilages. After this, the thigh bone may be cut or broken across, or lengthways, to show the outer, dense, or *compact* layer, and the inner, open, or *cancellated structure*, of which the bones are composed, and also the soft, vascular, and fatty tissue, called the *marrow*, found in the cells of the latter. The upper limbs, with their muscles, which need not be specially dissected, may next be partially detached from the sides of the trunk, and reflected outwards.

It will now be observed, both by the aid of sight and touch, that whilst the forepart of the trunk is ribbed at the sides and front, the hinder part has soft walls. The ribbed part is the *thorax*, the soft part the *abdomen*. These two cavities should then be opened, much after the manner represented in regard to the human body in Fig. 13. To open the thorax, the ribs and their attached muscles should be first cut through down each side of the chest; then the lowest cut rib, say on the left side, should be traced forward, detached from the soft parts below it, and once more cut across upwards, near its anterior end; then the next ribs in succession upwards, with the intervening muscles, must be cut in the same way, until the lower end of the sternum is reached, when that too is to be cut across: the same is to be done on the right side. The bony and muscular flap thus formed, consisting of the sternum or breastbone, and of the attached portions of ribs, is next to be pulled upwards, and forcibly detached, or cut away from the parts beneath it, being raised up as high as the neck, and then removed entirely; at this step, the windpipe and great vessels should be felt or looked for, and certain muscles which cover them may be lifted upwards as high as they ascend in the neck and cut away. To open the abdomen, an incision may be first made through its membranous and muscular walls along the middle line; two semilunar cuts, sweeping round, one on each side, and following, first the lower borders of the ribs, then the sides of the abdomen, and then the upper margin of the pelvis, will circumscribe the entire soft front of the abdominal walls, which may then be lifted up, and detached by severing the remains of a sort of band, or *peritonæal fold*, which is one of the supports or *ligaments* of *the liver*. The *diaphragm* will be seen separating the chest from the abdomen.

In the cavity of the abdomen, after noticing the general smoothness of its lining membrane, or *peritonæum*, there will first be observed the *great omentum*, an apron-like peritonæal fold containing little masses of fat: this may be lifted upwards and cut close along its upper margin: the *small intestine* will thus be exposed. The *convolutions* or windings of this may next be traced downwards to its lower end, which will be found above the right groin, where, being first tied in two places about an inch apart, it may be cut across between the strings. The small intestine itself is now to be removed by cutting, from below upwards, through the peritonæal fold, called the *mesentery*, which holds it to the back of the abdomen, and in which the bloodvessels, absorbents or lacteals, and nerves of the intestine are supported; on reaching the more fixed upper part of the small intestine, it is again to be tied in two places and cut through; by which step, the detached part, consisting of the *jejunum* and *ileum*, may be entirely removed. The *large intestine* may now be traced, ascending along the right side, passing next across, descending along the left side, and then entering the pelvis. Its commencement is named the *cœcum*, and from this it will be found there proceeds an enormous blind-ended, spirally-marked tube or cul-de-sac, which is a highly developed cœcal appendage, and is represented by the little *vermiform appendix* only, in the human body; to this succeeds the *ascending*, *transverse*, and *descending colon*, the *sigmoid flexure* of the colon, and lastly, the *rectum*. The rectum being twice tied and cut across, the whole of the large intestine is to be removed. The solid reddish organ, *the liver*, with its bright-green *gall-bladder*, may now be examined; also the mode in which it fits up against the vault of the diaphragm, the way in which it is suspended to that structure, and the fact that it overlaps the stomach; it must be noted that it is much more deeply notched or divided than the human liver: it is to be drawn downwards and cut away by dividing the soft parts close to its surface all round. The *stomach*, known by its dilated form, but unlike the human stomach, marked off by a constriction into two parts, may now be examined; its connection above with the *gullet* may be determined by pulling upon it, or by pouring water, or passing a quill down the throat until it enters the stomach; its connection below with the *duodenum* should then be followed. The white glandular organ called the *pancreas*, or sweetbread, may next be traced, attached to the bent part of the duodenum, and reaching across to the left; and lastly the dark purplish organ called the *milt* or *spleen* will be found attached to the left side of the stomach itself. The gullet being now tied below the diaphragm, all these parts should be removed; when the two *kidneys*, more rounded than in man, with the *supra-renal bodies* surmounting them, their ducts or *ureters* leading from them, and the great *bloodvessels* in the middle line, viz., the abdominal *aorta* and the *inferior vena cava*, will come into view. The knotted cords of the *sympathetic nerve* will also be seen.

In the thorax, the *two* lateral compartments formed by the right and left smooth-surfaced *pleuræ* will be immediately observed, each containing its own *lung*, which light pinkish-white spongy organs will be found to have shrunk a little so as no longer to fill their respective pleural sacs; at the back part of each lung its attached portion or *root* will be discovered, upon which the pleura passes to cover the lung itself. By pulling on the roots of the lungs, their connection with the windpipe is easily proved, as that part is seen to move accordingly. Air should also be blown down through a glass tube into the windpipe, by which means the lungs will be instantly inflated. Between the two lungs and partly overlapped by them, is the *pericardium*, the bag or sac in which the heart is contained: this must be opened, to show the heart in its natural position, having its free point or apex turned towards the ribs, and its broad attached base directed towards the back. The pericardium may now be snipped away from the diaphragm, and also from the great bloodvessels, which are seen springing from the base of the heart, and passing upwards to the neck, and sideways to the roots of the lungs. The great bloodvessels at the root of the neck, branching some to the head, and others to the upper limbs, may next be divided, together with the windpipe, and then all these parts, with the heart and lungs, may be stripped off downwards: on being laid upon a board and examined from behind, the course of the *trachea* or *windpipe* and its two *branches* or *bronchi*, as they go to the lungs, may be distinctly traced. There remain in the thorax itself, the thoracic portions of the aorta and the gullet, the course of which last, from the neck down through the diaphragm, may be again demonstrated by aid of a quill. The diaphragm itself may now also be studied. It is useless to search for the *thoracic duct*, which, however, lies behind the gullet, upon the vertebral column. With care, the knotted cords of the *sympathetic nerves* may be found, one at each side of the spine.

The upper remaining portion of the windpipe may next be traced up to the cartilaginous box, called the *larynx*, and the gullet up to the *pharynx*. At the side of the face and neck, just between the lower jaw and the ear, will be found the principal *salivary gland*, called the *parotid* gland; another, the *submaxillary*, lies below the jaw in the neck. The lower jawbone may now be split or cut through in the middle line, and its right half detached from the parts beneath and taken away at the joint near the ear: this opens one side of the mouth, and pharynx; and the opening thus made should be extended down the gullet. The tongue with the *sublingual* glands being drawn aside, the slit-like aperture, called the *glottis*, which leads into the larynx and so into the windpipe, is seen; and also a small valve, called the *epiglottis*, which falls back from the root of the tongue over this opening. A quill passed backwards through each nostril will show the communication of the *nasal cavities* with the upper part of the pharynx. The *ear* should be removed as close as possible to the head, to show the *passage* leading into the temporal bone, which contains the *internal* chambers of the *ear*. The *eyelids* may be divided at their outer corner and reflected back, to show the position of the *eyeball*, with its muscles and stalk-like nerve, lodged in the *eyesocket* or *orbit*.

The cranium should now be opened by a transverse saw-cut, made carefully through the *bone* only, above the orbits, met by two others running back to the occipital foramen. The top of the skull thus separated is to be raised up in front by a blunt chisel, and pulled off forcibly backwards. The *dura mater* thus exposed is, with its smooth *arachnoid* lining, to be cut along the same line as the bones, raised up and snipped away. The soft pulpy *brain*, much smaller, and more pointed in front, than the human brain, and nearly smooth as compared with that (see Figs. 58 and 59), is then to be removed by being raised up in front, certain bloodvessels and all the nerves given off from its under surface being divided one by one, as they pass to their respective openings in the base of the skull: last of all, the thick prolongation from the base of the brain, down the spinal canal, called the *spinal cord*, will require to be cut across. The distinction between the *cerebrum* and *cerebellum* having been noticed, and the layer of *arachnoid* with the subjacent vascular *pia mater* still covering their surfaces,—the course of the spinal cord down the backbone may be either traced by cutting open the vertebral canal (a very difficult task), or a fine twig or wire may be thrust down to demonstrate the existence of a canal. It is from the sides of the spinal cord that the nerves of the walls of the trunk, and the nerves of the limbs are given off.

The practical information obtained by such an examination of the various organs in the body of a dog or rabbit, as is above prescribed, must now be transferred, as it were, to the study of the human organism. Beside those marked differences in the configuration of certain parts which have been incidentally mentioned, and others which will be obvious enough, it must by no means be forgotten that the muscles are paler, and their tissue softer, and that the intermediate areolar tissue, the ligaments, bloodvessels, and nerves, being on a smaller scale, have an apparently finer structure, than in man.

To guard against any misconceptions, or any confusion between the characters of the organs in the animal and in man, it will be well, at this stage, to re-peruse the previously given description and the woodcuts of the organs of the Human Body.

THE TEXTURES OF THE BODY.

GENERAL CONSIDERATIONS.

The different organs of the body, which we have now examined generally, are no more composed each of a uniform homogeneous material than is the body itself. On the contrary, every organ is built up of several very distinct elements which are called *Textures* or *Tissues*.

Thus, the heart, which speaking in general terms is said to be a hollow *muscular organ*, is really composed of the following parts. Externally, we find a thin reflected layer of the *serous membrane* called the pericardium, which itself consists of a basis or web of dense *areolar connective tissue*, covered with a stratum of *epithelial tissue;* next beneath this is the proper substance or striped *muscular tissue* of the heart, which is mixed with a very minute quantity of fine areolar tissue; deeply seated in the interior of the heart are certain rings, cords and valves or flaps composed of *fibrous connective tissue;* and the internal surfaces of its cavities are lined with a thin smooth membrane, named the *endocardium*, which is like a serous membrane in its nature, being composed of a very fine layer of *areolar connective tissue* covered with a very delicate *epithelium*. Besides this, the heart has its proper *bloodvessels* and *absorbents*, all of which have their component tissues, viz., *areolar*, *elastic*, *unstriped muscular*, and *epithelial tissues*. Lastly, there are the *nerves* and *ganglia*, which consist of the *nervous tissues*, supported by sheaths of *areolar connective tissue.* So on all the organs of the body.

Of late years, under the name first of General Anatomy, and, now, of *Histology* (ἱστος, *histos*, a web, and λογος, *logos*, a discourse), these tissues or textures have been very minutely studied by aid of the microscope and certain chemical reagents; and it is truly remarkable what a variety of beautifully adapted minute elementary tissues have thus been discriminated both in animal and in vegetable organisms.

TEXTURES IN THE TONGUE AND LARYNX OF A SHEEP.

The tongue, larynx and upper portion of the trachea or windpipe of a sheep, attached to a piece of the middle of the lower jaw-bone, being obtained from a butcher, a dissection like that represented in Fig. 16 may be readily made with a little care, the parts being first fixed with strong pins upon a piece of board, and then portions being removed from the right side of the organ. Examples of every kind of tissue will be met with in such a dissection; and, from it, as the tissues of the sheep more nearly resemble the human textures than those of the rabbit, their naked eye appearances, their mutual relations, and their adaptation to particular purposes, will be better understood preparatory to studying their microscopic characters in the human frame.

The solid walls of the larynx, *c*, and also the firm rings which nearly sur-

Fig. 16.

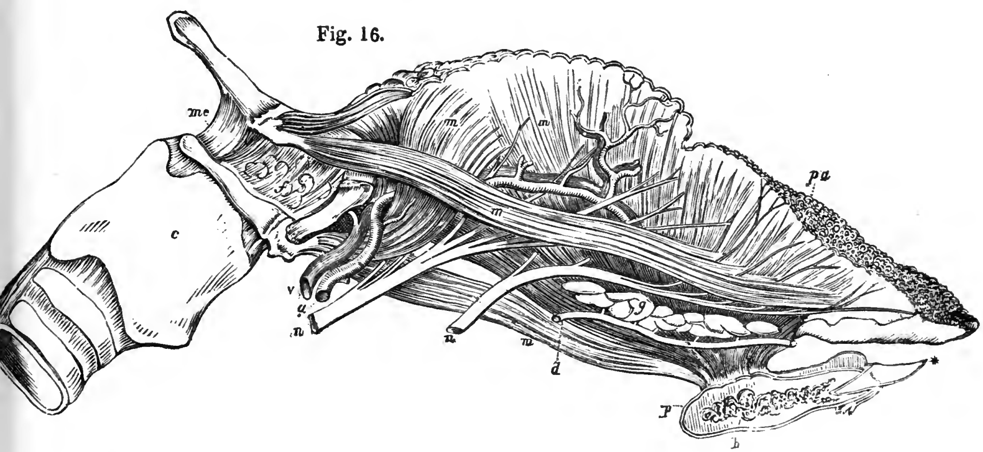

Fig. 16. A view of the right side of the tongue, larynx, and two upper rings of the trachea or windpipe of the sheep, attached to a piece of the lower jaw; the whole being dissected to show its constituent parts. *c*, the thyroid cartilage of the larynx: below this are two cartilaginous rings of the trachea, all being held together by intermediate membrane. Above the larynx are the several pieces of the hyoid bone and its adjuncts. *me* is a simple membrane, containing little lobules of fat, *f*. *m*, *m*, *m* are various muscles of the tongue. *p a* is the papillary mucous membrane by which it is covered. *a* is the lingual artery entering the tongue, and *v*, the lingual vein passing out of it; the branches of both vessels are seen in the substance of the organ. *n* (to the left) is the hypoglossal nerve, the muscular or motor nerve of the tongue: *n* (to the right) is the lingual branch of the fifth nerve, going to the mucous membrane, and constituting the sensory nerve of the tip of the tongue. *g* is the sublingual gland, one of the salivary glands, the ducts of which end in the larger duct, *d*, of the submaxillary gland, which is not seen here. The duct *d* opens into the mouth beneath the tip of the tongue. *b* is the section of the lower jaw-bone showing the cancellated structure, and containing one of the incisor teeth. *p* is the periosteum covering that bone. (The Author.)

round the trachea, afford an example of one variety of that white semi-opaque, firm, elastic substance, called *cartilage* or *gristle*. Parallel with the upper border of the larynx are the several pieces of the lingual or hyoid bone, which is large in the sheep, and presents us with an illustration of *osseous tissue*, which, however, is better exemplified in the lower jaw, *b*. Both the cartilages and the bones are covered with a so-called *fibrous membrane*, composed of *fibrous connective tissue*, named in the former case the *perichondrium*, and in the latter the *periosteum*, *p*. In the open or cancellated structure of the jaw-bone will be found some *marrow*. The tooth furnishes us with an example of *tooth-substance*, or *dentine*, of the *crusta petrosa*, and of the hard pearly *enamel* by which its smooth exposed part is covered. The rings of the trachea, the larynx, and the pieces of the hyoid bone are connected together by simple *membrane*, of which the piece marked, *m*, is a good illustration, consisting of dense *areolar connective* tissue; in it will be found examples of the little lobulated masses of *adipose tissue* or fat, *f*. Plenty of the loose form of *areolar connective* tissue is also found (in many places charged with fat), connecting the different parts, and surrounding and supporting them. In the junctions of the several pieces of the larynx (to be exposed by dissecting the piece, *c*, away from the rest) little joints even will be detected, united by *ligaments* composed of *fibrous connective* tissue, and lined by *synovial membranes*, consisting of a basis of *areolar connective tissue*, covered by a layer of *epithelium*. On examining the interior of the larynx it will be found that the slit-like opening called the *glottis* is bounded on each side by two yellowish-looking cords, the *vocal cords:* these are composed of nearly pure *yellow elastic tissue*. The valve at the root of the tongue, called the *epiglottis*, which projects over the aperture of the glottis, is made up of a mixture of *cartilage* and *elastic tissue*, or *yellow fibro-cartilage*.

Situated in the substance of the membrane composing the hinder flattened part of the trachea, where the rings do not reach, are transverse bands of a pale pinkish hue: these consist of the *unstriped* or simplest form of *muscular tissue*, such as is found in the viscera generally, excepting only the heart. The mass of the tongue consists of the *striped form* of *muscular* tissue, such as constitutes the flesh or muscles generally. As shown in the dissection, this striped muscular tissue is composed of bundles of soft fibres, which are collected into definite masses, or *muscles*, such as are marked, *m*, *m*, *m*, one radiating from the lower jaw throughout the whole tongue, another passing from the lower jaw to the hyoid bone, and others passing in form of three bundles from various points of the hyoid bony apparatus to different parts of the tongue,—one reaching to its very tip.

Entering the tongue at its side, near the root, is one of those bloodvessels which are called *arteries*, *a;* and passing out from the tongue near it is a *vein*, *v;* the branches of both being traceable far into the tongue, where they finally end in a common uniting network of those minute vessels, invisible to the naked eye, named *capillaries*. All the *blood* of the tongue in the natural state is contained within these three kinds of tubes or vessels. There are also *absorbents* belonging to the tongue, but these it is impossible to see. Two *nerves*, *n*, *n*, likewise penetrate the tongue, one of which, the hinder one, sends its fine branches into the muscular substance, being a muscular nerve; whilst the other, the forward one, gives off twigs which advance through the muscular substance to the surface of the organ, and supply the soft moist *membrane* or skin which everywhere covers it in the natural condition.

This membrane or skin is a *mucous membrane*. It is indeed only a part of that extensive mucous membrane which, commencing at the mouth and nostrils, passes from both points backwards into the pharynx, and thence into the larynx, and along the windpipe and its branches into every part of the lungs, and also down the gullet, along through the stomach and the rest of the alimentary canal. On the under side of the free part of the tongue, where it is continuous with the gums, this covering membrane is *smooth*, but on the fore part on the top of the tongue, *pa*, it is covered with little eminences called *papillæ*, or is papillated; further back it has larger papillæ, and is also provided with *mucous follicles* and *glands*,—little organs which secrete or form the *mucus* or general moisture of the mouth. The *saliva* is formed by more complex *secreting* glands, of which one called the *sublingual gland*, *g*, is shown in the dissection. It is a lobulated mass from which many short tubes or *ducts* proceed and enter a large tube or *duct*, *d*, beneath, which comes itself from the submaxillary gland, not shown in the figure, and opens on to the surface of the mucous membrane beneath the forepart of the tongue, where it discharges its salivary secretion or saliva into the mouth. These and all other *secreting* *glands*, as we shall hereafter see, are but appendages or extensions of the mucous membrane, which is prolonged into their ducts. The mucous membrane of the tongue is formed of a layer of condensed *areolar connective tissue* covered by an *epithelium*. Its epithelium is of the kind called *squamous*. The epithelium covering the mucous membrane of the interior of the larynx and windpipe is *columnar* and *ciliated*, i. e., provided with microscopic lash-like moving organs called *cilia*.

The tissues thus enumerated and demonstrated from the sheep's tongue and larynx may even be used for microscopical examination to illustrate the descriptions now to be given of the human tissues. A few special tissues, such as the brain substance, the substance of peculiar glands, and the parts of the organs of the senses, as well as pure articular cartilage, and white fibro-cartilage, may be taken also from the sheep. There is, however, no skin like the human skin.

In examining the tissues microscopically a common watchmaker's lens may be first employed upon them. Afterwards those tissues which are composed of filamentous or tubular elements may be prepared for the compound microscope by pulling or tearing asunder by means of needles, the constituent parts of a small portion, the size of a pin's head, placed in a drop or two of water on a piece of glass. Of the solid tissues a very thin section must be made, and put on glass in a drop of water. Thus prepared the specimens must be covered with the fine glass sold for that purpose, and then they may be examined under the compound microscope as transparent objects. The epithelial coverings of membranes merely require to be scraped off and moistened with a drop of water. Various reagents are employed to alter the tissues under examination, as will be mentioned hereafter. The order in which the several tissues will now be described is one of convenience only. The mode in which they may be classified will be stated in the physiological section of the work.

THE MICROSCOPIC STRUCTURE OF THE TISSUES OF THE HUMAN BODY.

Connective tissue.—This tissue exists in two forms, *areolar* and *fibrous*. The *areolar* form connects organs and parts of organs together, supports their vessels and nerves, and allows of a certain movement amongst them; it consists of a loose moist extensible web, composed of interlacing bundles and bands, having intervals between them called *areolæ* or *cells*, whence it is named also *cellulár tissue*. These areolæ communicate through the whole body, and are the spaces in which the fat is lodged, and in which fluid collects in general dropsy. Under the skin, and the mucous and other membranes, the areolar connective tissue is named *subcutaneous*, *submucous*, and so on. In a more condensed form it constitutes the basis of those membranes themselves.

The bundles of this tissue are made up of delicate transparent colorless *filaments*, Fig. 17, *a*, held together by moist homogeneous matter. The filaments are wavy, and do not branch; and the bundles interlace in all directions: hence the flexibility and extensibility of this widely spread and important tissue. Its resiliency is due to the intermixture of numerous exceedingly fine fibres of *elastic* tissue.

The *fibrous* form of the connective tissue consists of the same elements as the areolar form, viz., colorless filaments mixed with fine elastic fibres; but the white filaments, instead of being in open interlaced bundles, are arranged in close parallel ones, having a shining aspect, and marked with faint cross waves, Fig. 17, *b*. The fibrous tissues, therefore, are not loose and extensible, but strong, unyielding and glistening. Straight intersecting bands, held firmly together in one plane by areolar tissue constitute the *fibrous membranes*, such as the periosteum, the pericardium, the outer coat of the eyeball, the broader ligaments and tendons, and the strongest parts of the fascia

Fig. 17.

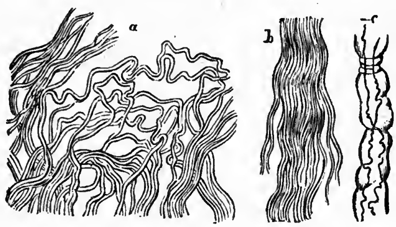

Fig. 17. *a*, interlacing bundles of colorless wavy filaments of the areolar connective tissue. *b*, parallel wavy filaments of the fibrous connective tissue. *c*, a single filament, swollen up after the addition of weak acetic acid, and showing certain fine dark fibres of elastic tissue coursing upon it. Magnified 400 diameters. (*a*, *b*, The Author; *c*, Kölliker.)

investing the muscles of the limbs. Straight parallel bands closely held together, constitute flattened or rounded *fibrous cords*, such as certain ligaments, and the long tendons of many muscles.

The areolar and fibrous tissues are not very vascular; nor have they many nerves. They are almost insensible, except when inflamed. Tendons and ligaments suffer, however, from being overstretched.

Elastic tissue.—This tissue is so named because it is not merely extensible, but *retracts* after it has been stretched, like vulcanized India-rubber.

The very fine elastic fibres, which, as already mentioned, are mixed with the filaments of the areolar and fibrous tissues, are best shown by treating these latter with acetic acid, which causes the white filaments to swell up to a great size, whilst the elastic fibres remain singularly well defined, appearing as dark lines lying upon and even sur-

Fig. 18.

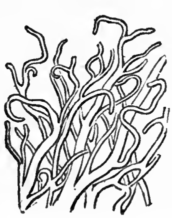

Fig. 19.

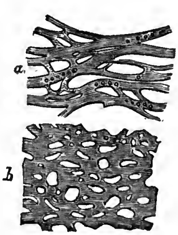

Fig. 18. Dark, clear, branching, interlaced and curly fibres of the elastic tissue. Magnified 200 diameters. (The Author.)

Fig. 19. *a*, a layer of elastic tissue, in which the component fibres are flattened and joined together so frequently as to form a very close network. From the pulmonary artery of a horse. *b*, a still closer network of the same kind, forming a perforated or fenestrated elastic membrane. From the carotid artery of the horse. Magnified 180 diameters. (Kölliker.)

rounding the white filament, Fig. 17, *c*. When present as the chief constituent of any part, the elastic tissue has a yellowish color; hence it is often called *yellow elastic tissue.* Its component fibres have remarkably dark outlines; they are never quite parallel to each other; they frequently branch and unite again; and when torn, their ends curl up, Fig. 18. In this form the elastic tissue exists in the two vocal cords of the larynx, and in certain peculiar ligaments of the spine. In the elastic coat of the arteries many of the fibres are flattened, and join together so frequently as to form a very close network, Fig. 19, *a*, or even a *perforated membrane*, Fig. 19, *b*. The elastic tissue is neither very vascular nor sensitive.

Adipose tissue or fat.—This tissue consists of numerous roundish or oval compressed vesicles, filled with an oily fluid and held in clusters by minute bloodvessels, and by the filaments of the areolar tissue in which they lie, Fig. 20. The fatty matter within the vesicles, though fluid at the natural temperature of the body, become more solid as this gets cool, and sometimes even partly crystallizes. In the state of emaciation, the fat vesicles become shrivelled and emptied of oil.

The fat acts as a filling or padding material in the body, between other parts; it also serves to smooth and round the outline of the form;

Fig. 20.

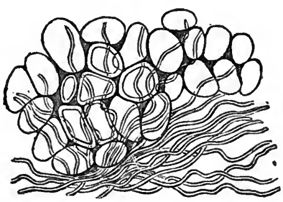

Fig. 20. Vesicles or cells of the adipose tissue or fat, supported by filaments of areolar connective tissue. The cells are supposed to be filled with an oily fluid. Magnified 100 diameters. (Sharpey.)

it acts as a non-conductor, by which heat is retained in the body; and it is a store of nutriment always available for use. It is more abundant in children and in females, than in adults and males generally. The circumstances causing it to vary in quantity will be hereafter discussed. Fat is never found within the skull, where its alternate accumulation and disappearance might interfere with the functions of the brain; nor in the lungs, whose action it would impede; nor in the eyelids, whose movements it would hinder.

The *marrow* of bones is chiefly a fine adipose tissue. Fat generally is a very vascular texture; but it is supplied with very few nerves indeed.

Cartilage, *fibro-cartilage*, and *yellow fibro-cartilage.*—Pure cartilage, or *articular* cartilage, such as covers the ends of the bones at the joints, is a firm, elastic opalescent substance, which consists of a homogeneous or faintly granular solid *matrix*, containing certain spaces in which are imbedded the rounded or compressed bodies containing little nuclei, and called *cartilage cells* or *corpuscles*, Fig. 21, *a*. Near the free surface of a cartilage these corpuscles are flattened out, but deeper they are arranged vertically, so that the cartilage splits more easily in that direction. In the cartilages of the larynx and windpipe, in the gristly part of the nose, and in the cartilaginous portion of the ribs, which are fixed to the breast-bone, the matrix is indistinctly striated. The cartilages of the ribs and larynx become bony in old age.

Fig. 21.

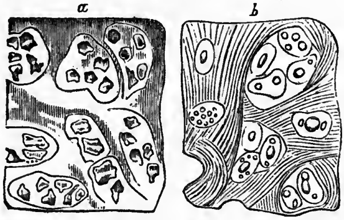

Fig. 21, *a*, a small piece of articular cartilage, from a joint, showing its solid matrix and the cartilage cells, with their little contained nuclei, embedded in it. *b*, portion of white fibro-cartilage, consisting of nucleated cartilage cells, embedded in a somewhat fibrous matrix. Magnified 260 diameters. (*a*, Sharpey. *b*, Kolliker.)

Fibro-cartilage may be regarded as a mixture of cartilage and fibrous tissue, or as a cartilage with a distinctly fibrous matrix, containing cartilage-corpuscles and nuclei, Fig. 21, *b*. It is found in certain joints, as will be hereafter explained.

In *yellow fibro-cartilage*, the fibrous part is soft and resembles *elastic tissue*. Examples of it are found in the ear, eyelids, and valve-like epiglottis.

Articular cartilage is absolutely without bloodvessels, *i. e.*, is non-vascular. The other kinds are all slightly vascular; and they also have a fibrous membrane investing them called the *perichondrium*, which is vascular. No nerves have been seen in them.

Osseous tissue or bone.—The outer so-called *compact* tissue of bone is not quite solid, but is traversed by minute tubes called the *canals of Havers*, which form a longitudinal network in the *bone-substance*, and open by minute pores on the surface. The finest canals are near the surface of the bone: further in, they get larger and at length open into obvious channels, which becoming still wider, form at length the *cancelli* of the spongy tissue, which finally merge, at least in the long bones, into the central cavity for the marrow or *medullary cavity*, Fig. 22, *a*. When more highly magnified, *b*, and Fig. 23, the bony substance surrounding these canals and cancelli, is seen to be arranged in concentric *laminæ* firmly united together, and having lying between them very minute cavities called the *lacunæ of bone* or *bone corpuscles*, from which numbers of exceedingly fine tubuli called *canaliculi*, pass into the solid substance of the laminæ, and connect neighboring lacunæ and Haversian canals. In the living state, the Haversian canals are occupied by small often capillary bloodvessels, which enter the bone from the periosteum, and communicate also with the bloodvessels of the marrow. Bone is therefore a very vascular tissue; most of its vessels reach it from the periosteum; but in the long bones, there is usually an artery for the medulla which enters the bone by a distinct orifice. A nerve enters at the same opening; but bone is not sensitive unless inflamed.

Dry bone consists of two-thirds of earthy matter and one-third of animal matter, the two being everywhere intimately blended; for the former may be removed by acids, and the latter by burning, without destroying the shape of the bone. In bone softened by acid, a fibrous

Fig. 22.

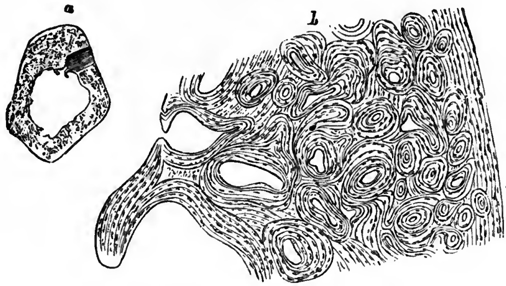

Fig. 22. (Sharpey.) *a*, cross-slice of the ulna, one of the bones of the forearm, showing the cavity for the marrow in the centre, and the pores in the surrounding bone. *b*, the dark piece of *a*, highly magnified, showing the canals of Havers, and the laminated structure of the surrounding solid bone. *a*, natural size; *b*. magnified 12 diameters.

structure can be shown in the laminæ. Healthy bone is a very strong material: it is somewhat elastic; and the hollows in its substance, besides facilitating its nutrition, make it mechanically better fitted for its purposes, by spreading out a given weight of substance into more space, and making it proportionally more resistant.

Fig. 23.

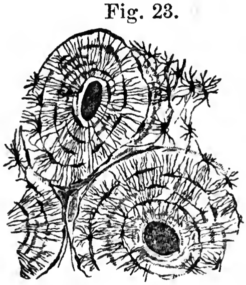

Fig. 23. (Sharpey.) A very fine section of bone, showing two of the canals of Havers, with the surrounding bony laminæ, between which are the little bodies called the corpuscles or lacunæ of bone, with fine lines radiating from them, called the canaliculi of bone. This section is supposed to be examined on a black ground, so that the hollow parts are dark, and the solid parts white. Magnified 90 diameters.

Muscular tissue.—There are two kinds of muscular tissue in the body, one consisting of *plain* or *unstriped muscular fibres*, and the other of *striped* or *striated muscular fibres.* The former kind is found in the walls of the alimentary canal, in the sides of the air-tubes and ducts of glands, in the skin, and in the coats of the bloodvessels and larger absorbent vessels. The latter kind forms the substance of the muscles of the body; but the substance of the heart also consists of an imperfectly characterized striated muscular tissue.

The *plain* or *unstriped* muscular fibres are soft, pale, smooth, and roundish or slightly flattened, Fig. 24, *a*. Their substance is indistinctly granular, as if composed of fine particles, called *sarcous elements* (from *sarx*, flesh), in or upon which are *elongated* bodies, or *nuclei*. When treated with diluted acetic acid, the substance of the fibre becomes transparent and the nuclei very distinct (see the fibre to the right). Nitric and chromic acids break them up into *fusiform bodies*, called *fibre-cells*, as at *b*, each including one of the nuclei, but being without a recognizable envelope or limiting membrane. In certain parts, as in the spleen of animals, in medium-sized bloodvessels, and in the skin, single fusiform fibre-cells exist; but, in most places, these are joined in an overlapping manner, to form the so-called plain muscular fibres. In the coats of the alimentary canal and elsewhere, these fibres form interlacing bands arranged in broad layers or tunics. Their extremities are never attached to the bone, but pass into bundles of fibrous connective tissue, and, in the gullet, have been seen to present

Fig. 24.

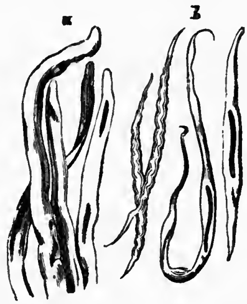

Fig. 24. *a* (The Author), portions of four plain or unstriped muscular fibres from the bladder; that on the right is rendered transparent, and its contained nuclei more evident, by being acted on by acetic acid. Magnified 170 diameters. *b* (Kölliker), two plain muscular fibre-cells from the pig's gullet, treated with nitric acid; one long one from the human intestine, and one from the coats of the dog's spleen, not treated with nitric acid. Magnified 200 diameters.

microscopic tendinous intersections. In the windpipe, they terminate in bundles of elastic tissue; in the skin, often on the sides of the hair-follicles.

The *striped* or *striated muscular fibres*, Fig. 25, are far more elaborately organized, presenting a much more definite and regular structure. They are soft, compressed or prismatic in shape, and marked with beautifully regular cross-lines or *striæ*. Each fibre is inclosed in a delicate glassy-looking structureless tube called the *sarcolemma*, as shown in the ruptured fibre, *b*; upon, or within, the sarcolemma, numerous nuclei containing one or more nucleoli are seen on the application of acetic acid. The soft substance of the fibre, transparent, and of a yellowish hue, consists of numerous fine threads called *fibrillæ* or *filaments*, *a* and *c*, which are themselves composed of rows of coherent quadrangular particles called *sarcous elements*. The existence of the fibrillæ gives rise to faint longitudinal lines in the fibres; whilst the equal size, the uniform arrangement, and the accurate adaptation of the sarcous elements, which act peculiarly on transmitted light, produce the more evident transverse striæ. Sometimes, even, as shown in *c*, a fibre splits into transverse discs opposite the intervals between corresponding rows of sarcous elements. When a single fibrilla is very highly magnified, its component row of oblong sarcous elements

Fig. 25.

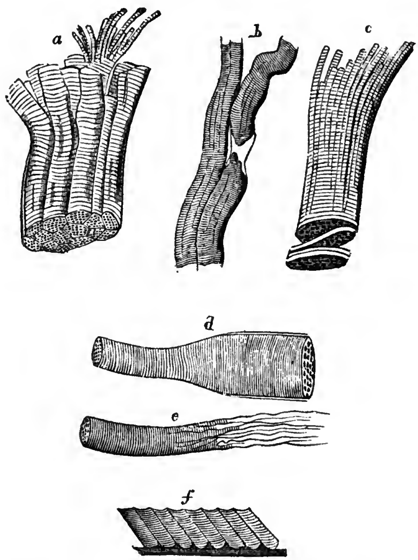

Fig. 25. *a* (The Author), a small muscular fasciculus, composed of parallel prismatic muscular fibres, marked with cross lines or striæ; one of the fibres is split into the finer threads called fibrillæ or filaments. *b* (Kölliker), two muscular fibres, one broken inside the tubular sheath called the sarcolemma. *c* (after Bowman), a single fibre more magnified, showing the longitudinal and transverse striæ; also the lateral adjustment of the sarcous elements of its component fibrillæ, which explains the cross striæ; and the occasional cross splitting of a fibre between rows of sarcous elements into discs. *d* (Bowman), a muscular fibre partly in a state of rest, and partly (to the left) in a condition of contraction. *e* (Kölliker), mode in which a muscular fibre changes, in becoming attached to, or continuous with, the fibrous connective tissue of tendons or periosteum. *f* (Kölliker), oblique insertion of muscular fibres into tendon. *a*, *b*, *d* and *e* are magnified about 150 diameters, *c* 300, and *f* 70 diameters.

presents alternate *dark* doubly-refracting, and *light* singly-refracting quadrangular portions, in the latter of which a delicate cross line is sometimes seen. The dark portions have been described as crystalline, and as being composed of minute doubly-refracting particles, named *disdiaclasts*.

In the formation of *muscles*, the fibres are collected into minute fasciculi or bundles, *a*, named the smallest fasciculi, which, again, are gathered parallelly into larger bundles, and these into still larger ones, as shown in Fig. 26. Each muscle is invested by a sheath of areolar tissue, named the *perimysium*, from which fine partitions of the same tissue, supporting the bloodvessels and nerves, pass inwards between the fasciculi and fibres. Most of the muscles are fixed to the bones, either directly or indirectly, by means of tendons; but, even in the former case, the individual muscular fibres are attached to the bone indirectly through the fibrous tissue of the periosteum. Some muscles, however, are fixed to soft parts, as to the tongue, lips, and eyeballs; either directly, as in the two former cases; or indirectly, by tendons, as in the last. In all instances, however, each fibre, as it ends, breaks up and merges into a bundle of fibrous connective tissue, either as shown in Fig. 25, *e*, or by first coming down obliquely on a tendon as in *f*. Usually the individual muscular fibres run along a fasciculus without branching; but in the tongue, lips, and face, they subdivide before they are lost in the submucous or subcutaneous tissue.

Fig. 26.

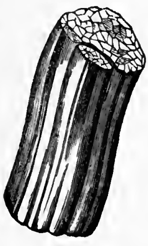

Fig. 26. (The Author.) A short piece of a compound muscular fasciculus, showing, on its cut end, its component little bundles, or ultimate fasciculi. Slightly magnified.

In the heart, the muscular fibres are striated; but the tubular sarcolemma is indistinct or absent. Moreover, the fibres themselves subdivide and unite again, so as to form a network; the bundles of fibres also frequently interlace; and, in some animals at least, fusiform nucleated fibre-cells have been seen amongst them. The heart substance, therefore, shares the characters of both the striped and unstriped muscular tissue. Moreover, these two forms of muscular tissue have another transitional or connecting link between them; for sometimes the unstriped fibres have their granules or sarcous elements arranged in rows as disdiaclasts, thus imperfectly but decidedly approaching the character of the striped fibre.

The striped or ordinary muscles are exceedingly well supplied with blood,—their minute or capillary vessels running between the individual fibres, and forming elongated meshes, as shown in Fig. 35, *a*. Lymphatic vessels are absent, or very few. The nerves of the striated muscles are likewise very abundant; they come from the cerebrospinal system: their mode of termination will be presently adverted to. (See Fig. 30.) The vessels and nerves of the non-striated muscles are not quite so numerous; their nerves are derived chiefly from the sympathetic system.

Nervous tissue.—The brain, spinal cord, and nerves consist essentially of the gray and white nervous substances which, besides connective tissue and bloodvessels, in which latter the gray substance is very rich, contain three distinct microscopic elements, viz., *nerve-cells* or *ganglionic corpuscles*, *gray* or *gelatinous fibres*, and *white* or *tubular nerve-fibres*. In some situations, growing cells, free nuclei, and granules are found, as, for example, in the cerebellum.

The *ganglionic corpuscles*, Fig. 27, are nucleated cells, that is, vesicular bodies containing, besides a pulpy matter, an eccentric roundish body or nucleus, inclosing one or more nucleoli, surrounded by colored granules. Some of these nerve-cells are rounded, others oval, some pyriform or pear-shaped, others caudate, and some stellate or provided with branched offsets, completely continuous with the cell-wall and the contents of the cell itself. They are found in the gray substances of the cerebrum and cerebellum, as *c*, *d*, *e*; in the spinal cord, *b*; in the knots or ganglia of the sympathetic nerve, *a*; and at the terminal expansions of the nerves of sight and hearing; also on the nerve-terminations in glands and perhaps elsewhere. They vary in size in different situations. The nerve-fibres usually pass amongst them, Fig. 29, *d;* and, whilst some of the branched offsets of the cells

Fig. 27.

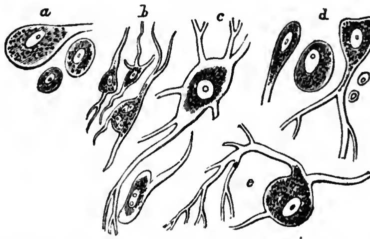

Fig. 27. (Kölliker and Hannover.) Colored cells, containing nuclei, called nerve-cells, ganglionic cells, or ganglionic corpuscles. *a*, cells of simple form from a sympathetic ganglion. *b*, branched cells, or stellate cells, from the gray substance of the spinal cord. *c*, branched cells of larger size from the medulla oblongata. *d*, simple and branched cells from the superficial part or convolutions of the brain. *e*, a large cell from the gray substance of the cerebellum. Magnified about 100 diameters.

serve undoubtedly to connect different cells together, others, it is stated, are continuous with the tubes of the white or tubular nerve-fibres. It is important to note, however, that this latter statement, though probably correct, is more a matter of inference than of direct observation, in so far at least as concerns the brain and spinal cord of man and the higher animals. In the ganglia, however, both in man and animals, this connection has been distinctly seen. According to the number of their offsets and connections, nerve-cells have been named *unipolar*, *bipolar*, or *multipolar*. Cells apparently destitute of them are described as *apolar*. The existence of such free cells has however been denied ; and the so-called unipolar cells are said to have another filament passing from them, often twisted round the one which is more evident (Beale).

The *gray* or *gelatinous fibres* (Remak's fibres) are very simple in structure, being soft granular flattish fibres, having no distinct tubular and medullary investment, and containing many dark nuclei, Fig. 29, *d*. These fibres are most abundant in the sympathetic nerve and its branches, but a few extend into the spinal and cranial nerves. Some of these are regarded as connective tissue fibres, and not as nerve-fibres at all.

The *white* or *tubular nerve-fibres*, Fig. 28, *b*, are microscopic tubuli, which when freshly examined in a perfect state appear to be homogeneous, but which, even on cooling, soon acquire a characteristic dark, smooth, double outline or contour, 1, and which may quickly, from pressure or other causes, become varicose or beaded, 2. Each tube consists of an outer *structureless membrane*, inclosing a layer of transparent fluid fat, or *medullary* matter, which, after death, 3, is apt to lose its clear homogeneous appearance, and become congealed into drops or masses, or to project from the broken or cut ends of the tubes. Within this medullary matter, or *white substance* of Schwann, as shown in Fig. 28, 4, is a firmer part or core, called the *central band-axis*, or *axis cylinder*, which is not fatty but albuminoid. This central band is very important, as it is sometimes the only part of a nerve-fibre left within the tubular structureless sheath, constituting thus the so-called pale *non-medullated* nerve-fibre. This axis is also

Fig. 28.

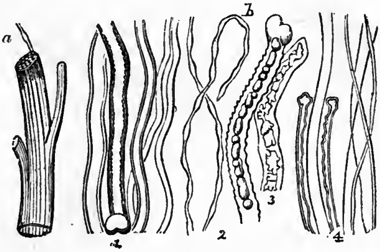

Fig. 28 *a* (The Author), portion of a spinal nerve giving off two branches, shown to be composed of a number of parallel cords called funiculi (of which one is seen projecting), inclosed in a sheath. Magnified slightly. *b* (Kölliker), white tubular nerve-fibres from different parts of the nervous system, in different states. Magnified 260 diameters. 1, five fibres of different sizes from nerves, three having the double outline. 2, two fibres which have become varicose after removal. 3, two fibres, the fatty contents of which have become altered by the action of water. 4, fibres from the brain: one large one, showing the outer tube, the central axis or cylinder projecting at the upper end, and the intermediate white or medullary substance. The four last fibres are remarkable for their fineness.

the part which is said to be continued into the delicate offsets of the branched nerve-cells, those processes being identical in structure with the non-medullated nerve-fibres. As the medullary substance in the tubular fibres forms a covering around the central band, it is spoken of as the *medullary sheath.* These medullated, tubular nerve-fibres compose the white parts of the brain and spinal cord, and the chief substance of the various nerves; but they also pass into and mix with the gray substance of the brain, cord, and ganglia. They vary much in size (see Fig. 28), being finest of all, 4, in the superficial layers of

Fig. 29

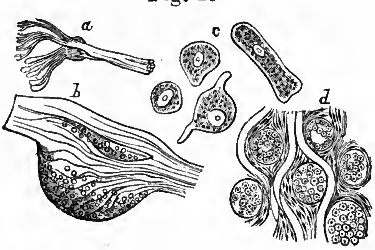

Fig. 29. (*a b*, Kölliker; *c*, *d*, Valentin.) *a*, origin of a spinal nerve from the spinal cord, by two bundles of funiculi, or two roots, which join to form the trunk of the nerve. On one of the roots,—the posterior one in the body,—is a small knot called a ganglion; the other, or anterior root, is seen to pass over the ganglion without entering it. *b*, section plan of a ganglion, showing the fibres of the posterior root passing amongst the ganglionic corpuscles, and the fibres of the anterior root passing over them. *c*, four separate ganglionic cells from a spinal ganglion, of different shapes. *d*, minute portion of a ganglion, showing six corpuscles, three white tubular nerve-fibres, and a number of the gray nerve-fibres or connective tissue fibres with little dark nuclei. *a*, natural size; *b*, magnified slightly; *c*, *d*, about 100 diameters.

the brain, fine in the nerves of special sense, and in the ganglia, larger in the fore part of the spinal cord, and largest in the motor nerves.

Within the gray substance of the nervous centres, the white nerve-fibres either commence from the processes of certain of the nerve-cells, or appear as loops running between those cells. Even in the latter case they may have their origin in cells not immediately under observation. Indeed, the view has lately been advanced, that *all* nerve-fibres originate in nerve-cells; and it has further been argued that, most probably, each cell is the centre of one or more complete circuits, a fibre or fibres passing from and returning to it again (Beale). As they pass out from the base of the brain, or from the sides of the spinal cord, the nerve-fibres form bundles of little cords, named *funiculi*, Fig. 29, *a*, which are soon gathered into a cluster or *nerve-root*. In the spinal nerves there are *two roots*,—one posterior, the fibres of which go through a knot or *ganglion* of gray substance, *a*, *b*, and one anterior, the fibres of which go past the ganglion; both sets join beyond the ganglion to form a single *nerve-trunk*. In the nerves, and their branches, Fig. 28, *a*, the tender funiculi are supported in bundles by the *neurilemma*, a soft sheath, having partitions in it, composed of a form of connective tissue, and continuous with the membranes of the brain or spinal cord. The bundles and even the funiculi often split and interlace, to form *nervous plexuses*, but the ultimate nerve-fibres, it is believed, do not subdivide, at least in their course, and remain of uniform thickness.

The nerves appear sometimes to end in loops, sometimes in *meshes*, but more frequently by *free extremities* with or without previous *subdivision*, in the various tissues to which they go. In the muscles, as

Fig. 30.

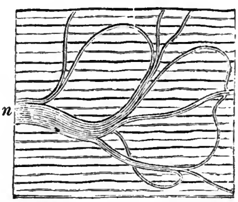

Fig. 30. (Burdach.) Plan of a thin portion of muscle, showing its parallel fibres slightly waved or zigzag; and a small nerve, *n*, composed of a bundle of white tubular nerve-fibres, which pass over and amongst the muscular fibres and form returning loops. Magnified 30 diameters.

shown in Fig. 30, white tubular *motor* nerve-fibres, once considered terminal, form rather wide loops, which cross amongst the muscular fibres; but, according to recent observations on the muscles of the lower animals, these loops are by no means the real terminations of the nerves. All agree that the dark-bordered or medullated fibres of the motor nerves give off very fine non-medullated branches, which either end in fine points, or else form a delicate network upon the muscular fibres; and these fibres are marked by numerous attached nuclei; and most authorities agree, that they do not penetrate within the sarcolemma. Other appearances have also been described, such as *terminal nerve-buds*, or blunt *knob-like* endings of the dark-bordered fibres, and more recently the so-called *terminal plates* of those fibres, from which non-medullated fibres arise. These terminal plates, one to each fibre, are said to be found only near the middle, not at the ends of a muscle; they are compared to certain parts of the electric organs of fishes; they are described as consisting of areolar tissue, as partially embracing a fibre, and as being placed at the point whence the non-medullated fibres are given off from the dark-bordered ones. The *sensory* nerve-fibres of muscles end also in pale non-medullated branches; but they are finer, and are distributed on the surfaces of the muscle, or of its principal bundles. In the papillæ of the tongue and skin the sensory nerve-fibres sometimes really form elongated loops; but here, as in other situations, they may lose their medullary substance and double contour, and perhaps even their tubular envelope, so as to be reduced to the axis or central band only, and then end amidst the tissues to which they are distributed,—either abruptly by swollen extremities, or after previously becoming finer and finer, or even after subdividing into fine twigs. The reticular mode of termination of the nerve-fibres has been observed in the retina of the eyeball, and in the submucous tissue of the intestines. Special modes of termination in the organs of sense, and, in certain bodies, the tactile and Pacinian corpuscles, in the skin, will be described hereafter.

The bloodvessels.—The three kinds of bloodvessels, *arteries*, *veins*, and *capillaries*, differ very much in their structure.

The *arteries*, the strong yellowish or white cylindrical branching tubes which proceed from the heart to all parts of the body, have thick elastic walls; so that they remain open when they are cut across. These walls consist of three coats, Fig. 31, *a*, viz., of an external coat, composed of areolar and elastic tissue; of a middle or muscular coat, the thickest, composed of unstriped muscular fibres, arranged circularly around the vessel, mixed with a very few elastic fibres; and of a thin smooth internal coat, consisting chiefly of a fenestrated or striated elastic membrane, Fig. 19, lined by the vestiges of a delicate epithelium, Fig. 43, *c*. The inner coat is brittle, and the middle one tender; the outer one is very tough; so that a string tied tightly round an artery cuts through the middle and inner coats but not the outer. The smaller arteries have relatively more muscular tissue, and the larger ones relatively more elastic tissue, in their walls. The outer and perhaps the middle coats of the arteries are themselves vascular, being supplied with nutrient bloodvessels, called the *vasa vasorum*. The arteries are supplied with nerves derived chiefly from the sympathetic system. In the limbs, all but the very finest arteries have a loose sheath of areolar tissue, in which they can be moved.

The *veins*, which, proceeding from all parts of the body, end in the heart, are more yielding tubes and have thinner walls than the arteries, so that they collapse when cut across. Their coats are also three in number, Fig. 31, *b*, and similar in general structure to those of the arteries; but the middle coat contains fewer unstriped muscular fibres, and the internal coat has no fenestrated layer, except in the veins of the pia mater of the brain, though it has fine elastic fibres and vestiges of a delicate epithelium, Fig. 43, *b*. In the largest veins, there are muscular fibres in the outer coat; and all the coats of the veins in the limbs, especially in the lower limbs, are thicker than elsewhere. Upon the great veins as they are entering the auricles of the heart, even a few striated muscular fibres may be found. The veins have their vasa vasorum, and a few nerves. Within many of the veins, at certain intervals, and also at the mouths of their branches, Fig. 31, are found little projecting folds or flaps, called *valves*, formed by the internal

Fig. 31.

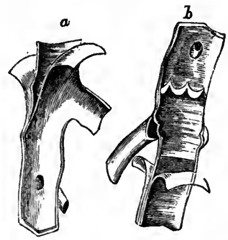

Fig. 31. (The Author) *a*, a portion of a medium-sized artery laid open, showing its three coats, viz., the external areolar coat, the middle muscular coat, and the internal elastic and epithelial coat. *b*, a piece of a medium-sized vein laid open, exhibiting its three coats. Besides this, it shows the valves in the interior of the vein.

coat, strengthened by a few fibrous bands. These are either single, double, or even three in number; and are always so attached that their free edge is towards the heart. They are most numerous in the veins of the limbs, especially of the lower limbs. Valves are not found in the smallest veins, nor in the largest, as the venæ cavæ; nor are they found in the pulmonary veins or hepatic veins, which return the blood

Fig. 32.

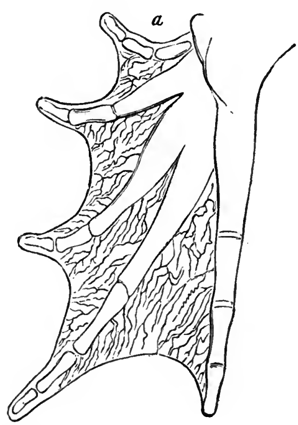

Fig. 32. (Allen Thomson.) Outline of the under surface of a frog's hind foot, to show the general branching of its small arteries and veins, in the web between the toes.

from the lungs and liver. They are also absent in the cranial, spinal, renal, portal, and a few other veins.

The *capillaries* are the intermediate vessels which connect the finest arteries with the finest veins. They are quite peculiar in structure. The arteries, branching out as they run from the heart into every vascular tissue of the body, become at last very small, and have very thin coats. Ultimately they end in a fine *network* of vessels called the *capillaries* (*capillus*, a hair), from which the smallest veins commence. These small veins at first have very thin coats, but, continually joining together to form larger and larger veins, at length run in a few main trunks to reach the heart again. The heart, arteries, capillaries, and veins form therefore a closed system of chambers and tubes, in which the blood is contained; and, as we shall see hereafter, whilst the heart and all the bloodvessels are concerned in conveying the blood through the body, it is the delicate capillaries only which permit nutritive material to pass from the blood through their coats into the tissues.

The ramified course of the bloodvessels generally is well seen in the web of a living frog's foot, Fig. 32; the capillary network itself in the same part becomes visible with the aid of a low magnifying power, as in Fig. 33; and under a much higher power, Fig. 34, the tubular character and distinct parietes of the capillary vessels, the mode in

Fig. 33.

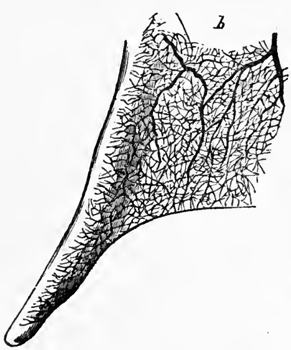

Fig. 34.

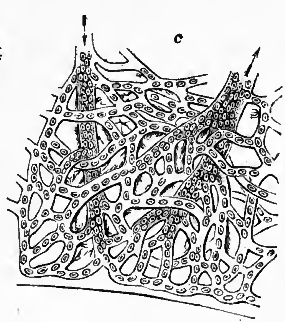

Fig. 33. (After Wagner.) A piece of the frog's web, with a portion of a toe, slightly enlarged, showing the fine capillary network connecting the terminations of the arteries with the commencement of the veins.

Fig. 34. (Allen Thomson.) Minute piece of the margin of the frog's web, showing the ultimate bloodvessels or capillaries, connecting the end of a small artery with the beginning of a minute vein. The oval blood-corpuscles are seen in these vessels, and the arrows entering and passing out of the artery and vein indicate the course of the blood-current. Magnified about 30 diameters.

which they connect the fine arteries and veins together, and their contained blood, are distinctly perceived.

In the vascular tissues of the human body also, the capillaries usually form a network, which may consist either of elongated meshes, as in muscle, Fig. 35, *a*, in tendons, and in nerves; of a polygonal network, as in smooth mucous membranes, *b;* of long loops, as in the skin, Fig. 36, *a;* or of close meshes, as in the small intestine, *b;* or of still closer meshes, as on the ducts of glands, Fig. 37. The finest meshes of capillaries are found in the lungs. The capillary vessels vary in size in the different vascular tissues: they are very large in bones, and smallest in the lungs and in the brain. The smallest capillaries, however, admit the little bodies which are found in the blood, called the red blood-corpuscles. Tissues which are destitute of capil-

Fig. 35.

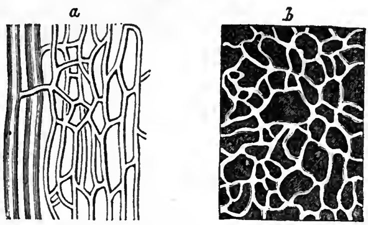

Fig. 35. *a* (Kölliker), capillaries of muscle, forming long meshes. *b* (The Author), capillaries of a smooth mucous membrane, forming large polygonal meshes. Moderately magnified.

Fig. 36.

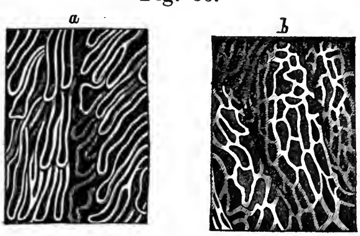

Fig. 37.

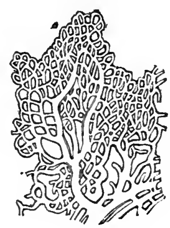

Fig. 36. *a* (Berres), capillaries of the papillæ of the skin of the tip of the finger, forming single loops. *b* (Berres), capillaries of the villi or little projections of the mucous membrane of the small intestine, forming small meshes. Moderately magnified.

Fig. 37. (Quekett.) Capillaries of the terminal extremity of a duct of the parotid gland, forming very close meshes. Moderately magnified.

lary vessels, such as the cartilages of the joints, certain transparent parts of the eyeball, including the clear coat or cornea, the substance of the teeth, the epithelial tissues, and the cuticle or outer skin and its appendages, the nails and hairs, are called *non-vascular*.

When a capillary vessel is very highly magnified, as in Fig. 38, its walls are seen to be exceedingly thin and delicate, and to be composed of homogeneous membrane in which many nuclei are set: on approaching the smallest arteries and veins, the capillaries gradually acquire extra coats and so pass into those vessels. The walls of all these small vessels are of course without vasa vasorum.

The blood.—The blood, the fluid contents of the bloodvessels, is of a bright florid color in the arteries, and of a dark purple tint in the veins. It is, apparently, a red homogeneous solution, but it really consists of a clear, limpid, almost colorless liquid, named the *liquor sanguinis*, the liquor or *plasma* of the blood, and of certain floating particles called *blood-corpuscles*. These latter are of two kinds, the *red* or *colored corpuscles*, and the *white corpuscles*. Blood also contains albuminous granules and fat particles, besides other occasional microscopic elements, such as clustered blood-corpuscles, pigment granules, and caudate cells, the chief of which will be described hereafter with the spleen.

Fig. 38.

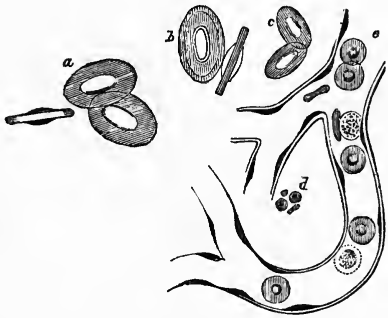

Fig. 38. *a* (Wagner and Kölliker), three red blood-corpuscles from the frog, one turned on its edge: they show the pale central nucleus and the outer colored part. *b*, two red blood-corpuscles of the monk-fish, one seen edgeways. *c*, two red blood-corpuscles of the common fowl. *d*, three minute red blood-corpuscles of the goat. *e*, human capillary vessel from the brain, showing its transparent walls and the nuclei embedded in them; and also seven red and two white blood-corpuscles within the capillary tube. Magnified 400 diameters, all on the same scale, to show the relative sizes of the different blood corpuscles.

The *red corpuscles*, which are present in enormous numbers, and on which the color of the blood entirely depends, are minute circular discs, Fig. 38, *e*, depressed a little on each side. Seen edgeways they appear rounded at the margins, and they are so soft and flexible as to bend easily around any obstacle (see Fig. 38, *e*). They are singly of a pale amber color; but, when collected in numbers, they produce a reddish hue. In blood, drawn from the vessels, the red corpuscles exhibit a curious tendency to run together into little rolls like coins: they are heavier than the plasma of the blood. Each corpuscle is usually regarded as a distinct vesicle, or so-called *elementary cell*, consisting of a very delicate elastic envelope or cell-wall, and a contained soft colored substance: the centre is clearer and paler, and looks like a central body or so-called nucleus, but in the perfect corpuscle there is no distinct nucleus.

Colored blood-corpuscles in animals.—In the mammiferous animals generally, the red corpuscles are also round, disc-like, non-nucleated bodies. In the camel tribe they are elliptical; in the deer and goat tribes, *d*, they are circular though small; they vary in size in different mammalia; and, so far as is known, are largest in the elephant, and smallest in the musk deer. In birds, *c*, reptiles, amphibia (frogs and newts), *a*, and most fishes, *b*, the blood discs are oval, and present a central elevation on each surface. They are larger in birds than in mammalia, still larger in fishes generally, and of yet greater size in the amphibia, being largest of all in the proteus. Their dimensions in a few animals will be given hereafter. In birds, reptiles, amphibia, and fishes, the colored blood-corpuscles are what are termed *nucleated cells*, possessing, besides an external envelope, a distinct projecting central body or *nucleus*, and an intermediate colored substance. In the frog, the nucleus occupies often one-third of the length of the corpuscle; as it is not visible when the corpuscles are still in the living vessels, it has been supposed by some to be the result of a subsequent process of aggregation within the corpuscle.

Many microscopic observers doubt or deny the existence of a cell-coat or envelope, not only in the human and general mammalian blood-corpuscle, but even in the larger corpuscles of the frog. They describe these bodies as little soft, elastic, homogeneous masses, having the outer layer a little more condensed than the interior, excepting the so-called nucleus when it is present. By some, the non-nucleated mammalian red corpuscles are regarded as free nuclei, specially modified (Gulliver, W. Jones); but it is said that they even possess a double cell-wall (Roberts); so that they might be regarded as small cells, completely filled by a vesicular nucleus.

The *white corpuscles* of the blood, much fewer in number than the red, the proportions between them averaging from 2 to 3 in 1000, are colorless, transparent and spherical *nucleated cells*, having no distinct envelope, but a finely granulated surface, granular contents, and, as shown by the action of acetic acid, a simple or compound nucleus in their interior, Fig. 38, *a*. They are not so heavy as the red corpuscles, and refract light more strongly. They do not run together into rolls like coins, nor do they change their form by bending within the vessels. Lastly, they are more uniform in size and shape in different animals than the red corpuscles, being nearly of the same size and character throughout, however widely the colored ones differ in these respects. They have a general resemblance to the corpuscles of the lymph, to be immediately described; but these latter are said, as we shall see, to be nuclei and not nucleated cells. After a meal, true lymph-cells also may be sometimes found in the blood.

White corpuscles in animals.—In the frog, the proportion of the white corpuscles to the red is 1 to 16 in winter, and 1 to 6 in summer. The singular little fish named the lancelet, or amphioxus, is the only one of the so-called vertebrate animals (of which it is the simplest yet discovered) in which the blood has no red corpuscles, but only colorless ones. The corpuscles found in the blood of still lower animals, such as cuttle-fish, insects, crabs, and others, are also generally free from color, and are usually discoid in shape.

When blood is diluted with water, the red corpuscles swell, become indistinct, and finally burst: when any agent, such as salt or syrup, which increases the density of the blood, is added to it, these same corpuscles shrink and assume various irregular forms. Sometimes, whilst being examined under the microscope, without any known cause, they become indented or jagged at the edges, or otherwise altered in shape. In certain cases this may be owing either to pressure, evaporation, special aggregation, or decomposition. The white corpuscles, on the other hand, have been seen to thrust out little buds, and so even become stellate, whilst they may yet be regarded as living. It has been said that oxygen gas distends the red corpuscles, whilst carbonic acid gas shrinks them up; but this is not well established. Acetic and other acids swell and ultimately dissolve them. The appearance of an envelope, and the pale nucleus or nuclei of the white corpuscles, are best seen after the action of very dilute acetic acid, when the corpuscle presents a smooth outline, and the nucleus often a reddish hue: very strong acetic acid causes the nucleus to divide into two or three separate parts.

When blood is drawn from its vessels, it sets, *coagulates*, or *clots*, separating into a red jelly-like mass, which is called the *clot*, and a thin fluid which oozes from the clot, named the *serum* of the *blood*. In the act of clotting or coagulation, the liquor sanguinis or fluid part of the living blood is said to separate into two parts, viz., into a small quantity of a solid substance called *fibrin*, which solidifies into minute fibrils, and a residual liquid part, of a pale yellowish hue, which is named the *serum* of the blood. Whilst thus separating and solidifying, the fibrin entangles in its meshes the red and white corpuscles of the blood, and so forms the *coagulum*, *crassamentum*, or *clot*, from which the serum runs out. The fibrin may be separately obtained by whipping freshly drawn blood for several minutes with a bunch of sticks, to which it then adheres in a stringy mass. The relative constitution of fluid and clotted blood may be thus expressed:

Fluid Blood.		*Clotted Blood.*
Liquor sanguinis	Serum	Serum
	Fibrin	
Corpuscles.	Corpuscles.	Clot.

The nature and cause of the coagulation of the blood will be considered in the chapter on the Circulation.

The absorbent vessels, or lymphatics and lacteals.—These vessels form a closed set of tubes distributed nearly everywhere throughout the body, and ending by the thoracic duct, and certain smaller trunks, in the great veins at the root of the neck (Fig. 100).

The finest lymphatics are supposed to commence on the surfaces of membranes, by a close network of delicate vessels, which are much larger than the capillaries, and have no direct or open communication with them. Those of the skin are represented, somewhat magnified, in Fig. 39. The mode of origin of the lymphatics arising in the interior of the muscles and of the organs generally, is not well known. In the tadpole's tail they have been seen as ramified vessels, shooting out many fine pointed processes. In the kidney of the mammalia, it is alleged that they commence in the lacunæ or spaces in the areolar connective tissue. The lymphatic vessels which course along the limbs or organs of the body, as shown in Fig. 100 are little delicate, transparent, varicose tubes, which escape observation unless they are distended with lymph or chyle, or are in some way artificially injected. Their appearance when distended is represented in Fig. 40, *a;* and when opened, as at *b*, a pair of valves is seen opposite each constriction. The edges of these valves are usually turned obliquely towards the terminations of the lymphatics in the veins; that is, in the ordinary direction of the fluid which flows along the absorbents; but they are said to be sometimes disposed transversely. The walls of the commencing lymphatics are homogeneous; but the large vessels, including the thoracic duct, have coats similar to those of the veins, composed of areolar, elastic, and even unstriped muscular tissue, and are lined by a fine epithelium.

The *lymphatic* or *absorbent glands*, or *lymphatic ganglions*, are the firm, oval or roundish bodies placed at certain points in the course of the lymphatics and lacteals (see Fig. 100). They are composed, as shown in Fig. 40, *a*, 3, of a number of imperfect cells or alveolar

Fig. 39.

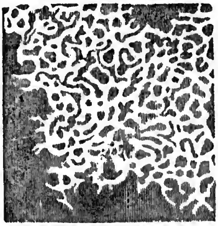

Fig. 40.

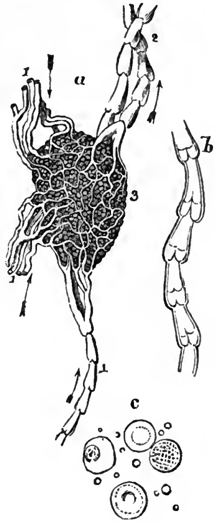

Fig. 39. (Breschet.) Network of the superficial lymphatics of the skin, injected with mercury. Moderately enlarged.

Fig 40. (Mascagni), *a*, plan of a lymphatic gland, 3, with its component cells filled with mercury, and having three sets of afferent vessels, 1, 1, 1, leading into it, and one set of efferent vessels, 2, passing out from it. The arrows indicate the course of the lymph in these vessels. The varicose or jointed appearance of the vessels is here shown. *b*, a single lymphatic vessel somewhat enlarged, and cut through, to show the little double valves in its interior. *c*, lymph corpuscles, one granular, and three treated with dilute acetic acid showing the envelope and the pale nucleus; also some finer granules and oil particles free. Magnified 400 diameters.

spaces filled with lymph or chyle, into which certain lymphatic vessels, called *afferent vessels*, *a*, 1, 1, enter, and from which other lymphatics called *efferent* vessels, 2, pass out, the whole being held together by intermediate areolar tissue, and inclosed in a proper areolar coat or investing membrane, which is perforated by the larger bloodvessels and absorbents. On a section, a lymphatic gland is seen to be made up, first, of an outer *cortical* part, composed of rounded or polygonal alveolar spaces or cells, from $\frac{1}{3}$d to $\frac{1}{8}$th of a line wide, and crossed by numerous trabeculæ, of fine *retiform* or *reticular connective tissue;* and secondly of a *medullary* part within, consisting of a fine plexus of lymphatic vessels. The afferent lymphatics enter the cortical substance at several points, and pass into its alveolar spaces, from which other finer lymphatics proceed, and form the plexus in the medullary or central part. From this plexus, the efferent lymphatics arise, and emerge from the gland frequently at a sort of fissure, sometimes named the *hilus*.

The *fluid* found in the lymphatic vessels is clear and colorless, but occasionally has a pale yellow hue; it is called *lymph*. It consists of a fluid part, or *liquor lymphæ*, which contains *nuclei*, minute *granules*, and, but seldom, a few *oily globules*. In the cells or alveolar spaces of the lymphatic glands, in the meshes between the trabeculæ, and in the efferent lymphatics beyond them, the lymph also contains a certain number of white, roundish, granular cells, or *lymph-corpuscles*, *c*, having an indistinct or doubtful envelope, and a pale nucleus within, which is rendered more visible by dilute acetic acid. These corpuscles resemble, outwardly, the white blood-corpuscles; but differ from them in being only large nuclei, and not nucleated cells. Strong acetic acid only acts slightly upon them, and does not split up the nucleus into separate bodies, as is the case with the nucleus of the white blood-corpuscles. They have been observed to put out little buds, and so to become stellate, whilst they may yet be supposed to be living.

The absorbents of the small intestines, called, from their milky-looking contents during digestion, the *lacteals*, have a similar structure to the lymphatics elsewhere. They commence, however, in a peculiar way, as will be mentioned hereafter in the section on Absorption. The milky-looking fluid which they convey during digestion, is called *chyle*, and is characterized by containing multitudes of fine granules, which are minute fatty particles enveloped by an exceedingly thin film of an albuminoid substance, and constitute what has been termed by Gulliver, the "*molecular basis of the chyle.*" Besides this, the chyle, after it has passed certain lymphatic glands, contains other granular particles, some nuclei, and also a few of the pale lymph-corpuscles just described. Drawn from the thoracic duct, or from the absorbent trunks near it, the lymph, or mixed lymph and chyle, coagulates like the blood, the clot of the former being transparent, and of the latter, of a milky color, and very soft consistence. Sometimes the lymph and chyle present a reddish tinge, owing to the accidental admixture of colored blood-corpuscles. The chyle, however, is supposed sometimes to have a proper red coloring substance formed in it: both fluids may become red on exposure to air.

The secreting membranes and glands.—The secreting membranes of the body, already generally described, are the *serous membranes*, the *synovial membranes*, the *mucous membranes*, and the *skin*. With these two latter membranes are associated the *glands*. Speaking generally, all these membranes consist of a layer of condensed areolar and elastic tissue, which is very thin in the serous and synovial membranes, thicker in the mucous membranes, and thickest of all in the skin. On its under or attached side this layer contains numerous bloodvessels, lymphatics, and nerves, all of which proceed to or from the free surface of the membrane. Near this there is found, at least in most situations, a thin stratum of a homogeneous structureless membrane, called the *limiting* or *basement membrane*. Resting upon this, or directly upon the condensed areolar layer, is invariably found a superficial stratum of *epithelial* or *epidermic* tissue, the character of which varies in different membranes, as will be presently described. The mucous membranes and the skin are much thicker, more specially organized, more vascular, and contain more nerves than the serous and synovial membranes.

The *serous membranes*, such as the arachnoid, pleura, pericardium, and peritonæum are transparent membranes arranged as closed sacs, smooth on the surface, and slightly moistened with a fluid which has been compared to the *serum* of the blood, but which resembles more closely the liquor sanguinis, for when collected in quantity it coagulates. They are covered with a single layer of flattened scale-like cells, constituting a very simple form of epithelial tissue, called the *squamous* or scaly epithelium. Fig. 43, *a*.

The *synovial membranes* lining the joints and the sheaths of tendons somewhat resemble the serous membranes, forming like them closed sacs; but they are thicker, have a thicker epithelium, and secrete a thicker fluid—the *synovia*. They are sometimes provided with *fringes* or projections, called, erroneously, *glands* (glands of Havers). Fig. 41, *a*, 1, 3.

The *mucous membranes* do not form closed sacs, but open directly or indirectly on to the surface of the body. The chief or most extensive mucous membrane in the body is named the "*gastro-pulmonary mucous membrane*," because it forms the lining membrane of the digestive organs and the lungs. Another mucous membrane, of smaller extent, lines the urinary passages and the cavities connected with

Fig. 41.

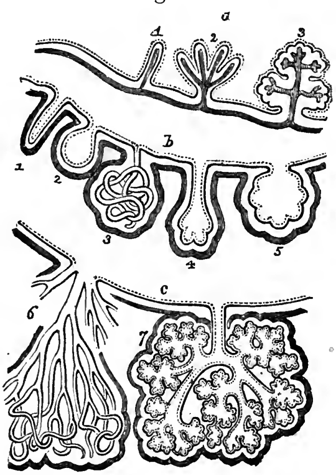

Fig. 41. (After Sharpey.) Three plans, *a*, *b*, *c*, of supposed sections of secreting membranes, to show the general arrangement of their component structures, and the way in which their surfaces are increased. In all three plans, the broad shaded line represents the areolo-vascular layer, the thin solid line is the basement or limiting membrane, and the dotted line the epithelial or covering layer. *a*, shows an increase by simple plaited or fringed projections. *b*, five modes of increase by recesses, forming five kinds of simple glands, viz. 1, a tubular follicle or *crypt:* 2, a saccular follicle or *sac:* 3, a coiled tube; 4, a *multilocular tube*, that is, a tube with depressions in it; 5, a *multilocular sac*. *c*, shows two forms of compound glands; 6, branched tubes forming a *compound tubular* gland; 7, branched tubes ending in little recesses or vesicles, forming a *compound racemose* or *conglomerate gland*.

them. The former membrane commences at the mouth, extends into the nose and between the eyelids, and into certain deep parts of the ear, and then passes downwards through the air-tubes into the lungs, and along the whole length of the alimentary canal. It is also extended in modified forms along the ducts of all the glands which open upon it. The mucous membranes consist of a fibro- or areolo-vascular layer named the *corium*, generally limited at its surface by a very thin transparent *basement* membrane, which again is covered by a layer of epithelial tissue. They are always of a deep red color during life, owing to their vascularity; but being thick and somewhat opaque, as compared with the serous or synovial membranes, they often have a pale pinkish brown hue after death. Sometimes a mucous membrane is thin and smooth, as within the nose and air-passages, or it may be thicker, as inside the cheek and throat. Sometimes it is *papillated*, that is, covered with eminences called *papillæ*, as on the tongue; or *villous*, that is, provided with softer projections called *villi*, as in the small intestine; or it may be thrown into *rugæ* or ridges, as in the stomach, or developed into folds or *valves*, as in the small intestine. In some places the mucous membranes are *recessed* into little *tubes, follicles* or *sacs*, simple or branched, Fig. 41, *b*, *c*, and so form minute *glands;* or, this formation of branched recesses being carried to an immense extent, larger compound glands are formed.

The mucous membranes secrete a slightly viscid moisture called *mucus;* and from their simple or complicated glandular recesses are formed *all the varied kinds of secretions*, such as the saliva, bile, gastric juice, tears, &c., excepting only those which come from glands similarly constructed, but existing in connection with the skin, such as the sweat glands, the sebaceous glands, and the mammary glands.

Fig. 42.

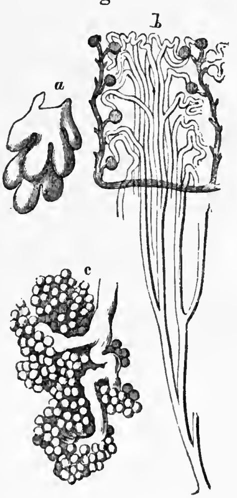

Fig. 42. *a* (Everard Home), multilocular gastric follicle from the proventriculus of an ostrich. *b* (after Kölliker), section through the substance of the kidneys, showing the branching tubuli, with their free or looped extremities, and the little rounded vascular bodies, called the glomeruli, connected with the tubuli. *c* (Müller), minute portion of the parotid gland injected with mercury, to show its terminal ducts and vesicles. All the figures are slightly magnified.

The different methods and degrees in which the surfaces of secreting membranes generally, are multiplied within a given space, are illustrated in the plans shown in Fig. 41, the description of which should now be referred to.

The simple and fringed projections, *a*, 1 and 3, occur in the synovial membranes; the plaited form, 2, in the interior of the eyeball. The *simple* forms of *glands*, *b*, 1 to 5, viz., the short tubule, follicle, or *crypt*, the wide follicle or *sac*, the long *coiled tubule*, the *multilocular tubule*, and the *multilocular sac*, are met with in special organs, which we shall have hereafter to describe, as in the stomach, intestines, eyelids, nose, ear, and skin. The *compound* forms of *glands*, *c*, are represented by the kidneys, 6, and by the mucous, lachrymal, salivary, and other glands, 7. A good example of a *multilocular sac* occurs in the follicles from the proventriculus, or secreting part of the stomach of the ostrich, Fig. 42, *a;* an instance of a compound or branching *tubular gland* is seen in the human kidney, *b;* whilst the ultimate lobules of a salivary gland, *c*, with their terminal ducts and vesicles, form a good example of a *compound racemose vesicular gland*, or *conglomerate gland.* There is still another form of gland, in which the ducts begin by a *network,* as occurs in the liver of man and the higher animals, which may be called a *reticular* gland.

The glands are even more vascular than the mucous membranes, of which they may be regarded as extensions. It is especially to be noted that, in no case, is there any direct or open communication between the capillary or other bloodvessels, and the terminal ducts or vesicles of the glands.

The epithelial and epidermic tissues.—These (so named from Greek words which signify that they cover other parts, viz., ἐπί, epi, upon, τίθημι, tithemi, I place, and δέρμα, the skin) are the *non-vascular* covering tissues which form and, as it were, finish off the actual surfaces of the various secreting membranes and the skin. They all consist of numerous agglutinated microscopic particles which are named *nucleated cells,* because they are more or less vesicular, and always contain a smaller transparent body called a *nucleus,* which is itself at one time vesicular, and frequently includes one or more still smaller granules called *nucleoli* (see Figs. 43 and 44). These nucleated cells vary in shape and size; they are sometimes arranged in one and sometimes in several layers, and cohere together by a minute quantity of intermediate substance.

Sometimes, as in the serous membranes, Fig. 43, *a* (taken from the

Fig. 43.

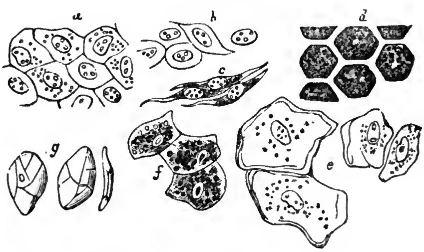

Fig. 43. (Henle and Kölliker.) Various forms of epithelium cells, magnified about 200 diameters. *a,* polyhedral squamous epithelium from the peritonæum. *b,* fusiform squamous epithelium from the interior of a vein. *c,* the same from an artery. *d,* hexagonal pigment epithelium from the black coat inside the eyeball. *e.* large squamous epithelium from the mucous membrane of the mouth. *f,* soft polyhedral glandular epithelium from the liver, or the so-called hepatic cells. *g,* horny, dry, transparent cells of the epidermis or cuticle. In nearly all the preceding cells, nuclei, nucleoli, and granules are seen.

peritonæum), the epithelial cells are flat and polygonal, lying in a single layer, and fitting edge to edge like little scales, or portions of pavement; hence such an epithelium is called *squamous* or *scaly, tessellated* or *pavemented.* Sometimes the cells of the stratified epithelium, as in the lip, tongue, and conjunctiva of the eyelids, and also those of the epidermis, are marked with fine lines, or *striated;* and again the deeper cells are occasionally covered with minute ridges and furrows, or with small spines, so as to be finely *denticulate* at their borders. In other situations, as in the interior of the veins, *b,* or arteries, *c,* the separate cells are *fusiform.* In the interior of the eyeball are certain *hexagonal* cells, *d,* which contain much dark coloring matter, and are called *pigment cells.* The pigment in them exists in the form of minute colored granules. Still larger scaly epithelium cells, *e*, exist in the mucous membrane of the mouth, throat, and gullet, where they lie in several layers or are *stratified.* This is also the case on the inner surface of the eyelids, where the deeper cells, as shown in Fig. 44, *c*, 4, are round; the next above them are oval or compressed, 3; the next somewhat flattened, 2; and the superficial ones quite thin or scaly, 1. In the epidermis, cuticle, or outer skin, which is raised in blistering any part, the cells also exist in many layers; they are quite flat, Fig. 43, *g*, on the surface only, where they have a peculiar, dry, horny character. The appendages of the cuticle, viz., the nails and hair, are also formed of modified epidermoid cells. There is a peculiar kind of epithelium called *spheroidal* or *glandular*, because its soft cells, often filled with granular matter, are roundish, and are found in the glands, *i. e.*, in the smallest or ultimate ducts of glands (see Fig. 91): sometimes, as in the liver, the glandular epithelium cells, Fig. 43, *f*, are compressed on all sides or *polyhedral.* When the spheroidal epithelium joins any other variety, whether squamous or columnar, the cells gradually change their shape accordingly, and thus is formed the *transitional* epithelium. Another form of epithelium is called *cylindrical* or *columnar*, Fig. 44, *a*, *b*, from the cylinder- or column-like shape and perpendicular arrangement of its component cells. This kind is found in the stomach and on the little projections, called villi, in the small intestine. The group, *a*, 1, Fig. 44, shows a single row of columnar cells attached at one end; 2, six

Fig. 44.

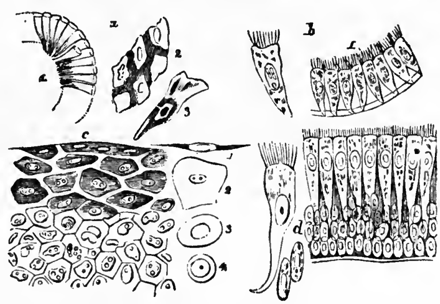

Fig. 44. (Henle and Kölliker.) Various forms of epithelium cells, magnified about 200 diameters, excepting *a*, 1, which is less magnified. *a*, columnar epithelium from the surface of a villus of the small intestine; 1, cells attached to a part of a villus; 2, six cells seen at their free ends; and, 3, a single cell viewed sideways, showing the central nucleus. *b*, row of ciliated epithelium, and a single cell enlarged, from one of the smaller air-tubes. *c*, stratified squamous epithelium from inner surface of the eyelid in the calf, showing in mass and separately, 4, 3, 2, 1, the changes in form from the deep to the superficial cells. *d*, stratified columnar ciliated epithelium, with several detached cells from the mucous or lining membrane of the trachea or windpipe.

cells seen at their free ends; and 3, a single cell more highly magnified: the outer ends of these are said sometimes to be finely channelled or perforated. In certain situations, as in the air-passage through the nose and throat, and in the air-tubes of the lungs, this columnar epithelium is covered with minute soft thread-like appendages named *cilia*, attached to the free ends of the cells, and is hence called *ciliated columnar* epithelium, *b*. By some the soft homogeneous substance composing these cilia is considered to be sarcodous. In the windpipe, this sort of epithelium is *stratified* or has many layers of cells, *d*, the superficial ones only being columnar and provided with cilia. In certain cavities in the interior of the brain, the epithelium is said by the best authorities (though it is doubted by some observers) to be ciliated, but the cells are flattened, not columnar. In some animals, too, a spheroidal tubular epithelium is met with, having cilia upon it, as in the roof of the frog's mouth.

There are some special tissues, or modifications of tissue, such as the *teeth*, *nails*, and hair, the humors and other parts of the eye, and certain parts of the ear and nose, which will be described hereafter. The structure of the different *secreting glands* will be considered in the chapters treating of their *respective* functions; and so, likewise, will the structure of those organs which, from their general resemblance to the secreting glands, have also been called glands, viz., the *ductless* or *vascular glands*, or *blood-glands*, which include the spleen, supra-renal bodies, thyroid body, and thymus gland, and also the *closed saccular* glands of the alimentary canal, represented by those of the tongue and tonsils, by the solitary glands of the stomach and intestines, and by the so-called Peyer's glands found in the small intestine only.

General View of the Structural Elements of the Tissues.

If now we glance generally at the numerous elementary microscopic constituents of the tissues, we find that, however, varied they may be, they are all referable to one or other of the following terms: *intermediate connecting* substance, named *blastema* or *matrix*, *crystals*, *protoplasm*, *granules*, *homogeneous* or *structureless membrane*, *vesicles*, *nuclei*, *nucleated cells*, *simple fibres*, *nucleated fibres*, *compound fibres*, and *tubes*. The blastema or matrix may be either fluid, as in the case of the liquor sanguinis of the blood, or softish, as in the moist tissues; either abundant, as in the soft forms of connective tissue, scanty, as in some epithelia, or absent, as in a peculiar reticular kind of connective tissue, found in the lymphatic glands and elsewhere; or the matrix may be dry and scanty, as in the cuticle, or abundant and fibrous, as in the connective tissues, homogeneous, as in pure cartilage, or fibrous and calcified, as in bone. Crystals are rare except in disease. Protoplasm is the soft, minutely granular substance, so universal in both the animal and vegetable kingdoms, and the earliest recognizable form of organic matter. Separate elementary granules are present in the chyle, the blood, the brain-substance, the pigment-tissue, and elsewhere. Elementary vesicles, consisting of fatty matter, exist in the chyle, the blood, and the milk. Free nuclei occur in the cerebellum, and are also represented in the lymph corpuscles. Structureless membrane forms the basement-membrane of the mucous tissues and glands; also the walls of certain nucleated cells, and the coats of the finest capillaries. Nucleated cell-tissues are represented by the white and early stage of the red blood-corpuscles, by the epithelial and epidermic cells, the pigment cells, the cells of the adipose tissue, and by the ganglionic corpuscles of the gray nervous substance. A nucleated cell is said to consist of an outer part or *periplast*, and certain contents, named the *endoplast*, lying in which is a *nucleus*, and within that, often, a *nucleolus*, or *nucleoli:* sometimes the periplast or envelope is indistinct or absent; and the entire cell may be soft, or firm, or even dry. Nucleated cells having an envelope, such as the epithelial cells and red blood-cells, might be conveniently termed *cystoplasts;* whilst the naked cells, without envelopes, such as the white blood-corpuscles, might be named *gymnoplasts.* The nuclei of these cells, and those found in the connective and muscular tissues, are regarded as nutritive centres, surrounded by protoplasm or germinal matter. Nucleated cells, embedded in solid blastema, occur in cartilage and in bone. Ramified or branching cells with nuclei, form the so-called connective tissue corpuscles. The fibres of the areolar, fibrous, and elastic tissues, are usually said to be produced by the fibrillation of intercellular substance. Mixtures of such fibres, with cartilage cells, form the white and yellow fibro-cartilages. Nucleated cells, elongated, perhaps joined, and composed of a peculiar substance, form the unstriped muscular fibres, and the gray or gelatinous nerve-fibres of the sympathetic system. Compound fibres, themselves derived from the union and modification of several nucleated cells, occur in the highly organized striped muscular fibres, and in the white or tubular nerve-fibres. Lastly, the commencing lymphatic vessels, and the capillaries, are examples of tubular tissues derived from the junction of ramified nucleated cells. The larger bloodvessels and lymphatics, and the ducts of glands, are really compound structures, or organs, built up of several tissues: so too, of course, are the various membranes, the glands and the organs of the senses, and such large organs as the brain, heart, and lungs.

Size of the Structural Elements of the Tissues.

Perhaps the best practical notion may be formed of the extremely minute size of the objects we have just been considering and describing, by reflecting on the statement that the red blood corpuscles of man are on an average $\frac{1}{3300}$th of an inch in diameter, and about $\frac{1}{4}$th of that or $\frac{1}{13000}$th of an inch in thickness: in other words, 3300 of these little bodies placed side by side would occupy one inch in length, and 13,000 piled one on the other would stand just an inch high. About 1300 red corpuscles would be necessary to cover the dot of this letter, i, and upwards of ten millions to cover a square inch of paper. A cubic centimetre, or $\frac{6}{100}$ths of a cubic inch, of human blood contains upwards of 5,000,000 of red, and 14,000 of white corpuscles. (Vierordt.) The red blood corpuscles may be taken as a rough standard of comparison in measuring all the other microscopic objects met with in the tissues; but these corpuscles vary in size, even in the same person, some being as much as a third larger or smaller than the average. The following is a list of the chief objects,

—with their respective *average* diameters in parts of an inch. They are arranged nearly in the order of their complexity of organization.

	Average size in parts of an inch.
Granules of the chyle,	$\frac{1}{35000}$
Corpuscles of the chyle and lymph,	$\frac{1}{2500}$
" of the blood, white,	$\frac{1}{2500}$
" " red,	$\frac{1}{3300}$
Epithelial cells of peritonæum—squamous,	$\frac{1}{1000}$
" mouth—ditto,	$\frac{1}{600}$
" intestines—columnar (length),	$\frac{1}{2000}$
" trachea—ciliated (length),	$\frac{1}{2000}$
Cilia (length),	$\frac{1}{3000}$
Epidermic cells,	$\frac{1}{800}$
Pigment cells of eyeball—hexagonal,	$\frac{1}{1000}$
" granules,	$\frac{1}{20000}$
Fat cells,	$\frac{1}{450}$
Nuclei of cartilage cells,	$\frac{1}{3000}$
Canals of Havers in bone (medium size),	$\frac{1}{500}$
" (extremes)	from $\frac{1}{1000}$ to $\frac{1}{200}$
Lâcunæ or bone corpuscles (width),	$\frac{1}{3600}$
" (length),	$\frac{1}{1800}$
Canaliculi of bone (width),	$\frac{1}{7000}$
Connective fibres,	$\frac{1}{15000}$
Elastic fibres,	from $\frac{1}{20000}$ to $\frac{1}{4000}$
Unstriped muscular fibres,	from $\frac{1}{7000}$ to $\frac{1}{3500}$
Striped muscular fibres (male),	$\frac{1}{350}$
" (female),	$\frac{1}{450}$
Filaments of these fibres,	$\frac{1}{10000}$ to $\frac{1}{18000}$
Ganglionic corpuscles of brain,	from $\frac{1}{3000}$ to $\frac{1}{300}$
Gray nerve fibres,	$\frac{1}{5000}$
White tubular nerve fibres (medium),	$\frac{1}{6000}$
" (extreme),	from $\frac{1}{12000}$ to $\frac{1}{1500}$
Terminal non-medullated nerve fibres,	$\frac{1}{10000}$
Capillaries, large, in bones,	$\frac{1}{1200}$
" small, in lungs,	$\frac{1}{3000}$
Lymphatics of skin,	$\frac{1}{800}$

Red Blood Corpuscles in Animals.

Mammalia.

Elephant,	$\frac{1}{2700}$
Sloth,	$\frac{1}{2800}$
(Human corpuscles, $\frac{1}{3300}$.)	
Ape,	$\frac{1}{3400}$
Dog,	$\frac{1}{3500}$
Wolf,	$\frac{1}{3600}$
Ox,	$\frac{1}{4200}$
Cat,	$\frac{1}{4400}$
Horse,	$\frac{1}{4600}$
Deer,	$\frac{1}{5000}$
Sheep,	$\frac{1}{5300}$
Goat,	$\frac{1}{6300}$
Musk Deer,	$\frac{1}{12000}$

Birds.

Various species (length),	$\frac{1}{1700}$ to $\frac{1}{2400}$

Reptiles.

Various species (length),	$\frac{1}{1200}$ to $\frac{1}{1500}$

Amphibia.

	Average size in parts of an inch.
Frog (length),	$\frac{1}{1000}$ to $\frac{1}{1200}$
Siren (length),	$\frac{1}{420}$
Proteus (length),	$\frac{1}{330}$

Fishes.

Various species (length),	$\frac{1}{1150}$ to $\frac{1}{2450}$

SPECIFIC GRAVITY OF CERTAIN ANIMAL FLUIDS AND TISSUES, WATER BEING 1000 DEGREES.

Chyle,	1024
Lymph,	1037
Blood,	1052 to 1057
" Serum,	1028
" Red corpuscles,	1088
Adipose tissue,	932
Brain substance (white),	1009
" (gray),	1030
Muscular tissue,	1020
Cartilage,	1150
Bone,	1870 to 1970
The entire body,	1065

The specific gravity of the glandular organs and their secretions is given with the descriptions of those parts and fluids.

THE PHYSICAL PROPERTIES OF THE TISSUES.

It is scarcely necessary to state here, that the materials of the body have all the physical properties of matter generally, such as weight, cohesion, extensibility, inertia, impenetrability, and so forth. Specially, however, we have to notice that, with the exception of the extreme outer layer of the cuticle, and the hairs and nails, every part and tissue of the body is *moist*. Even those parts contain a small quantity of water. With the above-mentioned partial exceptions, all the tissues are exceedingly *permeable* to that element or to solutions of which water is the main constituent; and when dried, as may be exemplified in the case of a piece of dried flesh, tendon or bladder, they very greedily reabsorb their lost quantity of fluid, when placed in circumstances in which they can do so.

The physical characters of all the animal tissues, indeed, are largely, nay, essentially, dependent on the presence of the water contained, not only in the fluids or intermediate moist blastema, but also in the very substance of the more consistent tissues. Thus it is their *contained* or *essential* water which endows all the soft textures, membranes, and organs with the requisite *suppleness*, *flexibility*, and general *elasticity* or *resiliency;* whilst their relative *mobility* amongst or over each other, is secured by their different degrees of *softness*, and by the presence of the intermediate moisture. The toughness or *cohesiveness* of all the consistent tissues, even of bone itself, also demands a certain proportion of combined or constituent water. Finally, the *special* or peculiar India-rubber like *elasticity* possessed, and exhibited, even after death, by the hence so-called yellow elastic tissue, is a purely physical property, which is manifested only so long as the tissue itself retains a sufficiency of its combined water.

The remarkable *permeability* of the animal tissues, and we may add, of vegetable tissues also, to water and watery solutions, is a character which, physically considered, is, to a certain extent, dependent on the previous natural existence of water in them; for had they been saturated with some other fluid, as oil, for example, they would have resisted the percolation of water and watery solutions. The phenomena attending the passage, in opposite directions, of water, and of various substances dissolved in that fluid, through dead organic membranes, described by Dutrochet under the designations of *Endosmosis* and *Exosmosis*, and more recently by Graham, under the terms *Osmosis* and *Dialysis*, will be considered in the chapter on Absorption.

THE CHEMICAL COMPOSITION OF THE BODY.

If the tissues and organs of the body are subjected to various processes of chemical analysis,—either by being allowed to coagulate, or by being coagulated by means of heat; by being washed or boiled in water for a long time, or by being dried and treated with alcohol and ether, certain products being then obtained by filtration and evaporation; or lastly, by being burnt to ashes,—it is found that they yield a number of substances which are called the *proximate constituents* of the body, because they are the first chemical compounds into which the several tissues may be made to resolve themselves. Some of these being peculiar to organized bodies are named accordingly, the *organic proximate constituents;* whilst others, found in the mineral kingdom also, are called the *inorganic proximate constituents.* The former, however, are by putrefaction or destructive heat, still further decomposed into ultimate chemical elements, which themselves belong to the mineral kingdom.

The Proximate Chemical Constituents of the Body.

The chief *inorganic* proximate constituent of the body is *water.* Next to this in quantity is *phosphate of lime.* Then the *carbonate of lime*, *chloride of sodium* (common salt), *chloride of potassium*, *phosphates*, *sulphates*, and *carbonates of soda and potash*, *phosphates* and *carbonates of magnesia*, *fluoride of calcium*, and certain compounds containing *iron*, *silica*, and *manganese*, besides traces of probably accidental substances, such as copper, lead, and aluminium. To these we must also add *ammonia*, which exists in combination with the urine, and likewise the gases named *carbonic acid*, *oxygen*, and *nitrogen.*

The *organic* proximate constituents are of two kinds. One kind contains the chemical element azote or nitrogen, and is hence called *azotized* or *nitrogenized.* These readily decompose and yield ammonia when they are burnt or putrefied. They are albumen and its allied substances, vitellin, globulin, and fibrin,—gelatin, chondrin, and elastin—mucus and horny matter,—extractive matters, crystallizable and non-crystallizable,—coloring matters, red and black,—a peculiar acid found in the brain,—the products of certain glands, such as casein, pepsin, salivin, and pancreatin (all of which are more or less allied to albumen),—and lastly, the biliary matters, and urea and uric acid. Another kind, not containing nitrogen, and hence called *non-azotized* substances, includes fatty matters of various kinds, blood- or liver-sugar, sugar of milk, sugar of muscle, lactic acid, and certain ingredients of the bile.

The azotized substances, generally, may be classed into the *albuminous* and *gelatinous* matters, *coloring* and *extractive* matters, and *secretory* or *excretory* substances. The non-azotized, taken generally, are either *oleaginous*, *saccharine*, or *acid* substances. The general characters of the chief of these substances will be first pointed out, and the constitution of the principal tissues will then be described.

Azotized Substances.—Albumen is the well-known substance which forms the *white* of eggs, whence its name, from *albus*, white. Natural albumen is soluble in water, and indeed exists largely in a state of solution in the blood of animals and man. It is then transparent, and may be dried at low temperatures into an equally transparent brittle mass. Its solubility appears to be somewhat increased by the presence of chloride of sodium (common salt), and perhaps of the alkaline phosphates and carbonates, in the blood. When, however, it is subjected to a heat of 142°, or, if in solution, to a heat of 158°, it coagulates or sets into an opaque white substance, which is henceforth insoluble in water. In solution, albumen is precipitated by alcohol, strong acids, and most metallic salts. When coagulated, it is dissolved by weak acids in excess, and by strong alkalies, and it is hardened by alcohol. Albumen is found chiefly in the fluid part of the blood, in the substance of the brain and nerves, and in the moisture which pervades the muscular and other tissues of the body: it exists also in the secretions of serous and synovial membranes, and in the lymph and chyle. A peculiar form of albumen, called *globulin*, is the chief constituent of the red corpuscles of the blood. Albumen is probably the root or source of all the other azotized ingredients of the body, and, together with fat, is the great nutritive substance of the animal economy. Vitellin is a modification of albumen, which is found in the yolk of the egg. It is thrown down by even weak acids.

Fibrin is the soft, whitish *stringy* substance which is obtained from freshly drawn blood, by beating or whipping it with a bundle of fine sticks or wires. It is closely allied to albumen, but differs from it in the very remarkable and singular property of *self-coagulation*, or *spontaneous coagulation*. In the act of coagulation, it concretes into minute threads or *fibrils;* whence its name. The nature of this process is not yet understood; it will have to be discussed hereafter, Fibrin is present in a state of solution, though, as compared with albumen, in very small proportion, in the fluid part of the blood; but it speedily coagulates when the blood is drawn from its vessels, and indeed is the material part concerned in the coagulation or clotting of the blood. Traces of dissolved fibrin also exist in the fluid of the chyle and lymph, and in the serous fluids. But it is in the muscular tissue that so enormous a quantity of a peculiar kind of fibrin is found, which is named *fibrin of muscle*, or *syntonin*, from συντείνω, *sunteino*, I contract. Like albumen, fibrin is precipitated, and then hardened, by alcohol: it is precipitated by mineral acids and most metallic salts; but is redissolved by dilute acids in excess. Blood-fibrin is soluble in a solution of nitre, but syntonin, or muscle-fibrin, is not. In the living body, as we shall hereafter find, both albumen and fibrin exist, sometimes in the solid and sometimes in the liquid state.

Gelatin is the substance of jellies, size, and glue. It is not proved to exist as gelatin in the living or dead body; but it is obtained as a product rather than as an educt, by boiling in water any part which contains white connective tissue, such as the areolar tissue, tendons, ligaments, the skin, and the areolar basis of the membranes generally. It is also obtainable from the animal matter of bones by long-continued boiling under pressure, as in a Papin's digester. From cartilages of a pure kind, a peculiar variety of gelatin, called *chondrin*, is extracted by boiling in water. No gelatin can be obtained by boiling blood, chyle, bile, gastric juice, saliva, milk, brain-substance, or muscle, except in the latter case, such as is derived from areolar tissue. Gelatin and chondrin do not coagulate. Gelatin, as its name implies, *gelatinizes* on cooling, and is liquefied or dissolved again by heat. One part of gelatin will gelatinize a hundred parts of water. Chondrin is also said to gelatinize, but this is doubtful. Neither gelatin nor chondrin is precipitated by the red or yellow prussiates of potash, by which they are distinguished from albuminoid bodies. They are, however, precipitated by alcohol, ether, corrosive sublimate, and by tannic acid or tannin, which is the active substance in converting any gelatin-yielding tissue, such, especially, as the skin, into the firm insoluble substance which we call *leather*. Chondrin is distinguished from gelatin, by being precipitated by acetate of lead, alum, acids, and a few salts, which do not throw down gelatin.

Keratin, or horny matter, exists in the hair, nails, and epidermis or cuticle, and also in the denser epithelia. *Mucin* exists in mucus, which is almost always acid.

Hæmatin, from αἷμα, *haima*, blood, is a red coloring matter, which is extracted from the red blood-corpuscles, with the globulin of which it is most intimately united. The compound formed by these two substances, named *hæmato-globulin*, has a great tendency to crystallize, even in blood simply set aside, but still more so in blood subjected to the successive action of oxygen and carbonic acid. The crystals from human blood are either prismatic or rhombic; from animals, tetrahedral, rhombohedral, and hexagonal crystals have been obtained. They are doubly refractive, soluble in acetic acid, ammonia, and water, and even deliquescent; but they are insoluble in alcohol. In blood extravasated within the body, there are frequently found flat, rhombic crystals, insoluble in water, acetic acid, alcohol, or ether, but soluble in chloroform. These are named *hæmatoidin*; the reactions of which with sulphuric acid resemble those of the bile pigments with nitric acid. Other crystals, named hæmatin and hæmin, have also been artificially obtained from blood. The so-called *hæmatin* is a deep red, almost black, substance, insoluble in water, alcohol, and ether, unless these be acidulated; it is readily soluble in alkalies. It contains a very large quantity of iron, nearly 7 per cent., but its color does not depend on the presence of this mineral. Hæmatin is now supposed to be a product of decomposition of the true coloring substance of the blood, which is named *cruorin*, and has a peculiar action on the solar spectrum. The green and yellow coloring matters of the bile, *biliverdin* and *bilifulvin*, seem to be somewhat allied to hæmatin.

Black or brown *pigment*, as found in the eye and in the negro's skin, is also peculiar in its composition. Both it and the hæmatin of the blood, have their color discharged or bleached by chlorine.

Casein exists in solution in fresh milk, and forms the substance of the curd of milk, and therefore of *cheese* (caseum), in which, however, it is mixed with more or less fatty matter or butter. Casein is very like albumen in its general properties, but, when pure and by itself, it will not coagulate by boiling. Its solubility appears to depend greatly on the presence of some alkaline or earthy salt having an excess of base. The pellicle which forms on the top of boiling milk is, in some way, owing to the action of the atmospheric oxygen. Acids, even when much diluted, readily coagulate it, hence the curdling of sour milk, in which lactic acid is developed; but its characteristic reaction is rapidly to coagulate by the addition of *rennet*, or the prepared mucous membrane of the fourth stomach of the calf: this is what takes place in the manufacture of cheese.

Pepsin is a very remarkable and potent albuminous substance, which exists in the gastric juice or secretion from the mucous membrane of the stomach of man and animals, and also in that membrane itself. From this it may be extracted by cold water, in which it is sparingly soluble. When slightly acidulated, especially by dilute hydrochloric acid, a solution of pepsin in water, at a low heat, rapidly brings about the solution of coagulated albumen, blood, and muscle-fibrin, meat, fish, cheese, and many other aliments. It does not dissolve the epidermoid or horny tissues, or the yellow elastic tissue, or pure fat. Its marvellous solvent property, or property of causing albuminous substances to dissolve in weak acids is, as we shall hereafter see, the source of the digestive power of the gastric juice. The peculiar properties of pepsin are destroyed by a boiling temperature, and by alkalies. Pepsin is precipitated in whitish flocculi, and rendered inert by alcohol: but the precipitate regains its solvent power when washed or again soaked in large quantities of water.

Salivin, or *ptyalin*, is a peculiar albuminoid substance found in the saliva. It has the very remarkable property (not altogether peculiar to it, however), of almost instantaneously converting starch into a kind of gum called dextrin, the dextrin into a form of sugar, and this sugar very soon into lactic acid. *Pancreatin* is the active principle of the secretion of the pancreas, which seems to possess the power of emulsifying fat.

The *extractive matters* mentioned above, in the list of azotized substances of the body, are yet but imperfectly understood. Amongst the crystallizable substances formerly confounded under the title, may now be reckoned *creatin* and *creatinin*, both of which exist in the juice of muscle and in the blood. The latter is also found in the renal excretion or urine, whilst the former occurs in the brain. Another substance, named *sarcin*, *sarcosin*, or *hypoxanthin*, is also found in the flesh and the blood. *Xanthin* occurs probably in all the soft tissues, and in the urine; it is allied to *guanin*. *Leucin* is another of these compounds, supposed to be the products of metamorphoses of albumen, and present in minute quantity in the body generally. *Tyrosin* occurs only in disease.

Amongst the azotized substances occurring in parts of the body only, must be mentioned one, named *cerebric acid*, which exists in the gray substance of the brain; and also the *cholic* or *glycocholic*, and the *taurocholic acids*, which are ingredients of the bile. These acids break up respectively, into *cholalic acid* and *glycocoll* or *glycocin*, and the same acid and *taurin*. Lastly, in the renal excretion, there are found large quantities of the substances called *urea* and *uric acid*, minute traces of which occur in the blood and soft tissues generally. *Urea* is a white crystallized substance, exceedingly soluble in water, to which it imparts a saline taste. It is remarkable that, though a product of living animals, it can be made artificially from organic matter, and is then known as a *cyanate of ammonia*, that is, a salt consisting of cyanic acid and ammonia. It acts as a base itself, however, and is capable of uniting with acids to form highly compound salts. *Uric acid*, normally existing in a state of solution in combination with ammonia or other bases, is easily precipitated in the form of minute crystals, and then is very insoluble. It constitutes the most common form of gravel and stone (hence its other name *lithic acid*, from λίθος, lithos, a stone), and is even excreted in a semi-solid form in birds, and in a solid form in serpents. *Hippuric* acid is said also to occur in human blood and urine; it exists largely in the urine of herbivorous quadrupeds.

Non-azotized Substances.—Of these, by far the most abundant are the various *fatty* matters, which are all distinguished by being insoluble in water, but soluble in pure hot alcohol and in ether. The principal seat of these fats is, of course, the adipose tissue; but fatty matters are found also in the brain and in muscle, in the blood, and especially in the chyle. The fat of the human body consists chiefly of olein, with a little so-called margarin dissolved in it. *Olein* is a fluid fat or oil, similar to that which constitutes the basis of olive, and some other oils. By being boiled with an alkali, as in the manufacture of soap, olein is separated into a fatty acid, called *oleic acid*, and a sweet viscid substance called *glycerin*, which of late years has become so familiar to all. *Palmitin* is a solid crystallizable fat, which is decomposable into *palmitic acid* and glycerin. In the fat of the sheep and ox, there is a third still more solid fat, *stearin*, which may be separated into glycerin and *stearic acid*. Margarin, another solid fat, is now supposed to be a mixture of stearin and palmitin. A fourth fatty substance, found in the brain, is named *lecithin*. Margarin melts at

114°, and stearin at 118°; whilst olein is fluid at ordinary temperatures, but solidifies at 50°.

Oleic, *butyric*, and probably some other volatile fatty acids, *propionic* and *caproic*, exist in the milk.

The so-called *glycero-phosphoric* acid is found in the brain: it is formed of phosphoric acid and glycerin. The phosphorus of the brain has also been regarded as occurring in combination with oleic acid, as an *oleophosphoric acid;* but this is doubtful.

Cholesterin is a sort of animal resin, which crystallizes in beautiful microscopic white scales. It occurs chiefly in the brain and in the bile, and forms the substance of most gall-stones. It also accumulates in certain *morbid fluids* and *diseased tissues.*

Starch and sugars of different kinds are found in the body. Thus, there is either an amylaceous, *sugar-forming* or *glycogenic* substance, named *amylin*, *glycogen*, or *hepatin* (from γλυκύς, *glūcūs*, sweet, and γείνομαι, *geinomai*, to become), or else a kind of sugar, named *glucose*, *dextrose*, or *grape-sugar*, in the liver, and in the blood of the veins which leave that organ. There is another kind of sugar in muscle, called *inosite.* Lastly, in milk, there is a large quantity of *lactin* or *sugar of milk*, which, in solution and in contact with azotized matter or a ferment, easily decomposes, and forms *lactic acid*, as happens in the souring of milk.

Lactic acid itself is also found in the blood as a lactate of potash or soda, in muscle, in the perspiration, and in the renal excretion. It is met with also in the gastric juice.

Formic and *acetic* acids exist in the perspiration, and sometimes *oxalic* acid in the urine.

The above-named saccharine and acid substances are all soluble in both water and alcohol.

The Chemical Composition of the several Tissues.

Such being the characters of the principal proximate organic and inorganic constituents of the animal body and its various fluids, it must be understood that these various substances may be extracted from, or shown to exist in, the different tissues, in certain definite quantities; in other words, that they may be obtained separately from each other, by taking advantage of their different behavior when acted on by water, alcohol, or ether, by evaporating their respective solutions in those fluids, and by drying or burning the tissues themselves. For example, the composition of the white substance of the brain is ascertainable by some such process as the following:

A given weight, sufficiently large to cover small errors, is first dried, at a temperature of 212°, in a water-bath, so as to show, by the loss through evaporation, the quantity of *water* it contained. The dried mass, cut or broken up, and then acted on by successive portions of ether, will yield to that fluid its *fatty matters*, which may be obtained separately, so as to be weighed, by allowing the ethereal solutions drawn off from the undissolved residue to evaporate spontaneously. Those residual undissolved matters acted on successively by hot alcohol, will yield to that menstruum, besides further traces of fat, certain *extractive matters* and *salts* (chlorides of sodium and potassium), which may be obtained by evaporating the alcoholic solutions, and would then have to be separated by special processes, and be weighed. The undissolved residuum, now acted on by boiling water, will yield to that fluid more *extractive matters*, and more *salts* (chiefly phosphates of soda and potash), which would have to be separated and weighed. The residue this time (insoluble in either ether, alcohol, or water), would consist chiefly of an *animal substance*, which would be found to be of an *albuminoid* nature, mixed however with *earthy constituents*. It would have again to be dried at 212° to expel the water, and then be weighed. This dried mass being now burnt in a covered vessel, the loss would indicate the quantity of albuminoid matter, whilst the ashes would consist of the earthy salts (phosphates, carbonates, and sulphates of lime and magnesia), which would finally have to be separated by ordinary chemical processes, and be weighed. In this way, all the proximate constituents of the white brain-substance, and their relative quantities, would be, though, after all, roughly ascertained.

We shall now briefly indicate the chemical constitution of the various tissues, reserving to special occasions the details of the composition of the different secretions.

The *connective tissues*, areolar, fibrous, tendinous, and membranous, including the basis of the skin, contain about two-thirds of water, and one-third of solid matter. The solid matter is nearly entirely resolved into gelatin on being boiled, but, like the blood itself, contains traces of alkaline and earthy salts.

Permanent cartilage contains about three-fifths of water and two-fifths of solid matter, which is resolved into chondrin on boiling. The solution gelatinizes on cooling, perhaps from the presence of a little gelatin. This cartilage contains from 3 to 4 per cent. of alkaline and earthy salts, chiefly carbonate and sulphate of soda, and carbonate of lime, but it also contains chloride of sodium and phosphate of magnesia and lime. *Temporary cartilage* yields a solution of chondrin, which does not gelatinize.

The *fibro-cartilages* have a mixed composition, yielding both gelatin and chondrin on being boiled. The *yellow elastic* tissue is said to contain less water than the other soft tissues. It offers great resistance to the action of boiling water, but at last yields, together with some gelatin, a peculiar substance named *elastin*, unlike both gelatin and chondrin; about one-half, however, is insoluble.

Recent *bone* contains nearly 10 per cent. of water. The animal part of dried bone constitutes 33 per cent., or one-third of its weight, and is convertible into gelatin on being boiled. The remaining two-thirds, or 66 per cent., are inorganic or mineral matters, and consist of 51 parts of tribasic phosphate of lime (or bone-earth), and 11 parts of carbonate of lime (chalk); the rest (a very small proportion) is fluoride of calcium (fluorspar), phosphate of magnesia, and chloride of sodium (common salt). The compact bony substance contains more earthy matter than the spongy bone; and also proportionally more phosphate to the carbonate of lime than the latter. In old age, the bones have been said to contain proportionally more earthy matter, but this is doubtful. In the disease called rickets, they contain less. In children, the carbonate of lime is, relatively to the phosphate, less abundant.

The purest form of the *muscular tissue*, the substance of the voluntary muscles, contains about 74.5 per cent., or nearly three-fourths of its weight of water. The remaining fourth, or 24.5 per cent., which is solid matter, consists of 15 parts of muscle-fibrin or syntonin, and of a residue, of which from 2 to 4 parts are fat, the rest being albumen (probably derived from moist fluid between the fibres, and the blood in the capillary vessels of the muscle), gelatin (derived from the intermixed fine areolar tissue), traces of a red pigmentary substance, a large quantity of extractive matters, such as creatin and creatinin, acids, and a quantity of alkaline and earthy salts, with some carbonic muscle-sugar or inosite, lactic, butyric, formic and acetic acid, and oxygen. The juice of muscle is acid. It contains more potash than soda salts, a large proportion of which are phosphates. The substance formerly called *ozmazome*, on which the odor of muscle depends, is a compound of several of the extractive matters.

The *white* and *gray nervous substances* resemble each other in containing, like the rest of the soft tissues, a very large percentage of water; the solid residue is composed of albuminoid matter, a large quantity of fatty matters, extractives, and salts. They differ from each other remarkably, in the relative proportions of their constituents. The white substance contains more solid matter and less water than the gray,—the percentage in the white matter being 73 of water to 27 of solid substances, and in the gray matter 85 of water to only 15 of solids. The white matter contains 15 per cent. of fat, the gray only 5 per cent.: the white has 10 per cent. of albuminous matters, the gray only $7\frac{1}{2}$: the extractive matter and the salts are about the same, the latter being chiefly phosphates. Amongst the albuminoid substances, is one said to resemble syntonin, and another which is compared to elastin. The fatty matters are partly reddish and partly colorless: they consist of cerebric acid (a peculiar azotized acid), glycero-phosphoric acid, lecithin, palmitin, palmitic acid, with traces of olein and some cholesterin. These fatty substances are supposed to be chiefly present in the medullary sheath, whilst the axis band is believed to contain the albuminoid syntonin. The extractives consist of creatin, xanthin, hypoxanthin or sarcin, and inosite, with lactic, phosphoric, and even uric acids, combined with potash, lime, and magnesia. There are also traces of oxide of iron, silica, alkaline sulphates, and chloride of sodium. The phosphorus specially contained in the brain amounts to from 1.3 to 1.79 per cent. of the weight of its substance.

The proximate constituents of the *blood* are so various, that, chemically speaking, it contains nearly all the substances found in the solid tissues, either as its essential constituents, or as unavoidable or occasional impurities. There is one very remarkable exception to this statement, in the total absence from the blood of any gelatin or chondrin, or of any substance which yields gelatin or chondrin on being boiled. In this respect, blood resembles pure muscular tissue and nervous tissue, and differs from the connective, cartilaginous, and osseous tissues. Blood has, indeed, been called *liquid flesh*, and it contains nearly as much solid matter as flesh, for the blood contains one-fifth, and muscle one-fourth, of its weight of solids. The analyses of the blood by various chemists, present very different results, partly due to the different methods employed, but also, doubtless, to the variable composition of this fluid, under different conditions connected with health, exercise, food, temperament, age and sex. Venous and arterial blood likewise differ in certain respects. The following table from Lehmann shows the composition of 1000 parts of blood, calculated from the analysis of venous blood by Lecanu:

	Corpuscles.	Plasma.	Total.
Water,	344.	451.45	795.45
Hæmatin,	8.375	—	8.375
Globulin and envelopes,	141.11	—	141.11
Fat,	1.155	.86	2.015
Extractive matters,	1.3	1.97	3.27
Salts,	4.06	4.275	8.335
Fibrin,	—	2.025	2.025
Albumen,	—	39.42	39.42
	500.	500.	1000.

According to this estimate, blood contains about 80 per cent. of water, and 20 of solid matter, the calculated proportions being about 79.5 and 20.5. In round numbers, of the 205 parts of solids, 156 belong to the red and white corpuscles, and consist of 141 parts of globulin (modified albumen), 8½ parts of hæmatin, the red coloring substance, 1 part of fat, 1½ of extractive matters, and 4 parts of salts, chiefly salts of potash. The remaining 49 parts of solids belong to the liquor sanguinis, plasma, or fluid part of the blood, and include rather more than 2 parts of blood-fibrin, which goes with the corpuscles in the act of clotting; the rest of these solids are proper to the serum of the blood, and consist of 39½ parts of albumen, 1 of fat, 2 of extractive matters, and 4½ of salts, chiefly salts of soda. Salts of lime and magnesia also exist in the blood, and likewise traces of silicon and manganese, and even of lead and copper. The soda, potash, lime, and magnesia, are variously combined, so as to form chlorides, phosphates, sulphates, lactates, and carbonates (at least when the blood is burnt to ashes). The distribution of the mineral substances in the blood is peculiar. Thus, the moist red corpuscles contain ten times as much potassium in 1000 parts as the liquor sanguinis, but only one-third as much sodium; whilst about six times more phosphoric acid may be obtained from the corpuscles than from the liquor sanguinis, but only about half as much chlorine. The chloride of sodium is, therefore, chiefly contained in the fluid plasma of the blood, and the phosphoric acid principally, and the potassium almost entirely, in the corpuscles, which also contain a large share of the fatty matters. In carnivorous animals, phosphates preponderate in the blood; in herbivora, carbonates abound; but the chloride of sodium is very constant in both, showing the strong affinity of the animal tissues for that salt. The albumen of the blood is by some believed to be combined with soda, as a so-called albuminate. The blood has a saline taste, and is an alkaline fluid, its alkalinity depending either on a carbonate or an alkaline phosphate of soda. The crystallizable extractive matters of blood consist chiefly of creatin and creatinin, but also include hypoxanthin or sarcin, leucin, tyrosin (in disease), hippuric acid, and even urea and uric acid in minute quantities. There are also, in certain kinds of blood, traces of grape sugar, or of the amyloid substance, glycogen, as in the blood of the hepatic veins, vena cava inferior, right auricle, and pulmonary artery. All blood contains traces of coloring substances like those of the bile, and odoriferous substances like those of the flesh. The odor of blood differs in different animals; in man it is said to be sometimes garlicky: it is supposed to be due to a fatty acid, and may be rendered more distinct by the addition of sulphuric acid, even to old specimens of dried blood. Lastly, the blood contains carbonic acid, oxygen, and nitrogen gases, in various proportions in different kinds of blood, and held in solution, or in some feeble state of combination, as will be more fully explained in the chapter on Respiration. The fluid plasma, which pervades all the tissues, must also hold in solution nearly all the constituents of the blood, including the gases just enumerated. Whilst the solid and liquid constituents of the blood are its nutrient part, the oxygen dissolved, or otherwise loosely combined in it, is its most energetic, chemical, and stimulating ingredient. The special uses of its several constituents will be considered in the chapter on the Circulation.

The *chyle* and *lymph* have a similar composition to blood, but they are both much more watery, and contain far less solid matter, the chyle being the richer of the two, that is to say, during digestion; but during fasting it has the same composition as the lymph. Chyle taken from a donkey has been found to contain about 900 parts, and human lymph about 970 parts, of water, in 1000. The 100 parts of solids in the chyle were found to consist of 36 of albumen, 4 of fibrin, 36 of fat, 15 of extractive matters, and 9 of salts. The 30 parts of solids in the lymph, consisted of $4\frac{1}{2}$ parts of albumen, 5 parts of fibrin, $2\frac{1}{2}$ of fat, 3 of extractive matters, and 15 of salts. Other analyses give different results; but the chyle, speaking generally, is distinguished from lymph, by containing more albumen, and much more fat; hence, after coagulation, the serum of chyle is more fatty than that of lymph. In comparison with blood, chyle contains much less albumen, but much more fat, and usually no coloring matter. The lymph of the lymphatics contains traces of sugar and urea; in the lymphatic glands leucin has been detected. The salts of the blood, chyle, and lymph, are very similar, only those of the blood are richer in phosphates. The lymph, like the blood, has a saline taste, and is alkaline; but the chyle is sometimes neutral, or only slightly alkaline.

The *serous* and *synovial epithelia* differ probably but little from albuminous substances; but the mucous epithelia, consisting of mucin, have more decided characters, approaching those of horn. The *epidermis*, and its appendages, the *nails* and *hairs*, consist chiefly of keratin with a little fat. Their ashes contain lime and iron, and those of the hair, traces even of silicon and of the metal manganese.

The chemical composition of the teeth, of the different glands, and of the various *secretions*, will be mentioned, with their uses and actions, in the physiological section of this work.

In reviewing what has been said concerning the proximate chemical substances which compose the various tissues of the body, one cannot fail to be struck with the fact that, with the exception of bone, in which the quantity is small, water enters so largely into the constitution of them all. Indeed, according to Moleschott, it forms about 68 parts out of 100 in the entire human body. The remaining 32 parts per cent. of dried substances consist, in round numbers, of 15 parts of albuminoid bodies, including albumen, globulin, syntonin, fibrin, and coloring substances, 5 parts of gelatinous and chondrinous substances, 2.5 of fatty matters, .5 of all the different extractive substances, including organic acids, sugar, and urea, and lastly, of 9 parts of salts, of which 1 perhaps is alkaline, and 8 are earthy.

The albumen and globulin are found, as will have been noticed, chiefly in the blood, chyle, lymph, nervous substance, and muscle; the syntonin and fibrin in the muscles, the blood, the chyle, and the lymph; the coloring matters in the blood, the eyes, the hair, and the bile; the gelatinous and chondrinous substances in the areolar and fibrous connective tissues, in the skin, the bones, and the cartilages; horny substances in the epidermis, nails and hairs; fatty substances in the adipose tissue, the brain, the blood, the chyle, and the bile; and extractive matters in most of the tissues and organs of the body. Of the alkaline and earthy salts, all occur in the blood; but the lime-salts are found principally in the bones and teeth, and much more scantily in cartilage; the magnesia salts occur in the bones, in the muscles, and in the blood; the soda salts, especially the chloride of sodium, in every tissue, but markedly in the blood-plasma; whilst the potash salts are found in the blood-corpuscles, and in the muscles. The fluoride of calcium exists in the bones, in the teeth, and in milk; silica chiefly in the bones and the hair; and iron principally in the blood. Carbonic acid and oxygen must occur everywhere, but mainly in the blood.

As to the water, combined in various measure with every tissue of the body, it is just as important, in regard to their chemical constitution and reactions, as we have seen it to be in reference to their physical characteristics, such as their softness, elasticity, and permeability. This *contained* or *essential* water, or *tissue-water*, as it might be called, also facilitates in an extraordinary manner, by its universal solvent power, all the requisite and incessant chemical changes which, we know, take place, not only in the more fluid, but also in the most solid parts of the living body. It is probable, also, that, just as in certain aqueous solutions of salts or other substances, the water appears often to be chemically combined with those substances, and not to be a mere solvent, so, in the changes from the solid to the fluid, or from the fluid to the solid state, of certain constituents of the body, water enters into combination with them, or leaves its state of combination with them, in definite proportions at various times. The vast importance of the chemical play of water in the living animal body, will be fully illustrated, as we proceed with our account of its vital properties and actions.

The subjoined Tables (from Dalton) show the quantities of water, of chloride of sodium, and of phosphate of lime, contained in 1000 parts of certain tissues, fluids, secretions, and excretions of the body. Some of these have not yet been here described.

Water, in 1000 parts.		Chloride of Sodium, in 1000 parts.		Phosphate of Lime, in 1000 parts.	
Secretions and Excretions.					
Saliva, ...	995	Mucus, ...	6.	Gastric juice, . .	.4
Perspiration, . .	986	Bile, ...	3.5		
Gastric juice, . .	975	Urine, ...	3.		
Urine, ...	936	Saliva, ...	1.5		
Pancreatic juice,	900	Milk, ...	1.		
Milk, ...	887				
Bile, ...	880				
Fluid Parts.					
Lymph, . . .	960	Vitreous humor, .	14.	Blood, ...	.3
Synovial Fluid, .	805	Aqueous ditto, .	11.		
Blood, ...	795	Blood, ...	4.5		
Solid Parts.					
Brain, ...	789	Bones, ...	2.5	Enamel of teeth,	885.
Ligaments, . .	768	Muscles, ...	2.	Dentine of do., .	643.
Muscles, . . .	750			Bones, ...	550.
Cartilages, . .	550			Cartilages, . .	40.
Bones, ...	130			Muscles, . . .	2.5
Teeth, ...	100				
Epidermis, . .	37				

The Ultimate Chemical Constituents of the Body.

The proximate chemical constituents of the body just described, whether inorganic or organic, are themselves, with the exception of the oxygen and nitrogen in the blood, not simple bodies, but compound substances formed by the union of other elementary bodies, which are therefore the *ultimate chemical constituents* of the body. For full details on this subject we must refer to *Treatises on Chemistry:* it will suffice here to state briefly, the chemical composition of the proximate constituents of the body.

As to the *inorganic* proximate constituents, their composition is comparatively simple; for they are usually made up of *two* elementary bodies, that is, they are *binary* compounds, such as water and salt, or else they appear to be formed by the union of two or more such binary compounds into one substance, as the carbonate of soda or the phosphate of lime.

If the oxygen and the nitrogen, which seem to exist free in the blood and other fluids, be really only dissolved in them, they afford examples of a simple element entering as such into the composition of the body; but it is possible that these gases are in some unknown though loose state of chemical combination in those fluids.

The carbonic acid gas is, however, a binary compound, consisting of one atom of carbon and two atoms of oxygen (CO_2, carbonic acid). Again, the water is composed of two atoms of hydrogen and one atom of oxygen, chemically combined as an oxide of hydrogen (H_2O, hydric oxide). The chloride of sodium (common salt) consists of one atom of chlorine united with one atom of sodium ($NaCl$, sodic chloride); chloride of potassium, of chlorine and potassium (KCl, potassic chloride); fluoride of calcium (fluorspar) consists of two atoms of fluorine and one of calcium (CaF_2, calcic fluoride). The alkalies, soda and potash, and the earths, lime and magnesia, are the oxides of the metals sodium, potassium, calcium, and magnesium, that is, are compounds each of one atom of oxygen with one or two atoms of those metals respectively (Na_2O, K_2O, CaO, and MgO, sodic, potassic, calcic and magnesic oxides). All the preceding bodies are binary compounds; but as examples of substances in the body, which appear to be formed by the union of two such binary compounds, we may mention the phosphates, sulphates, and carbonates of soda, potash, lime, and magnesia (otherwise named, the sodic, potassic, calcic, and magnesic phosphates, sulphates, and carbonates), which may be regarded as compounds of phosphoric, sulphuric, and carbonic acids with the abovementioned alkalies and earths,—carbonic acid being itself composed, as already stated, of one atom of carbon and two atoms of oxygen (CO_2); sulphuric acid, of one atom of the well-known substance sulphur, and three atoms of oxygen (SO_3); and phosphoric acid of two atoms of phosphorus and five atoms of oxygen (P_2O_5). The trace of silica or flint, found in the body, is an oxide of the metal silicon (SiO_2, silicic acid). The small but essential quantity of the metal iron (Fe) exists also in some combined state; and the minute traces of the metals manganese (Mn) and copper (Cu), and of alumina, the basis of clay, which is an oxide of the metal of aluminium (Al_2O_3), are perhaps accidental.

But the *organic* proximate constituents of the body have a much more complex chemical composition, though they too are resolvable by spontaneous decomposition, by chemical reactions, or by the destructive action of fire, into a few ultimate elements, which then revert to the inorganic state. The simplest of these organic constituents are *ternary* compounds, that is, they are formed by the combination of three chemical elementary substances; whilst others are *quaternary*, or even *quinary* compounds.

		Carbon.	Hydrogen.	Oxygen.
100 parts,	Stearic Acid ($C_{18}H_{36}O_2$), ... =	76.	12.7	11.3
"	Oleic Acid ($C_{18}H_{34}O_2$), ... =	76.6	12.	11.4
"	Margaric Acid ($C_{17}H_{34}O_2$), ... =	75.5	12.6	11.9
"	Palmitic Acid ($C_{16}H_{32}O_2$), ... =	75.	12.5	12.5
"	Glycerin ($C_3H_8O_3$), ... =	39.1	8.7	52.2
"	Cholesterin ($C_{26}H_{44}O$), ... =	83.8	11.9	4.3
"	Caproic Acid ($C_6H_{12}O_2$), ... =	62.1	10.3	27.6
"	Butyric Acid ($C_4H_8O_2$), ... =	54.6	9.1	36.3
"	Glycogen, or Animal Starch ($C_6H_{10}O_5$), =	44.4	6.2	49.4
"	Lactin or Sugar of Milk ($C_{12}H_{22}O_{11}$), . =	42.1	6.5	51.4
"	Glucose, Dextrose, or Grape Sugar ($C_6H_{12}O_6$), ... =	40.	6.7	53.3
"	Lactic Acid ($C_3H_6O_3$), ... =	40.	6.7	53.3
"	Acetic Acid ($C_2H_4O_2$), ... =	40.	6.7	53.3
"	Formic Acid ($C_2H_2O_3$), ... =	32.4	2.7	64.9
"	Oxalic Acid, or Hydric Oxalate ($C_2H_2O_4$), ... =	26.7	2.2	71.1

Thus the non-azotized substances, fat, sugar, and the animal organic acids, are ternary compounds, each consisting of certain quantities of carbon, hydrogen, and oxygen, combined in definite proportions. The *percentage* composition of some of these substances is stated above. The small figures attached to the letters between the brackets, show the numbers of so-called atoms of each element, which are supposed to enter into combination to form a particular substance; in other words, they show the theoretical *atomic* composition of that substance. But the percentage composition, representing in round numbers the quantities by weight of each element in 100 parts of the substance, is also of some interest.

The great characteristic of fats is, that they are very rich in carbon and hydrogen, in proportion to their oxygen; they are known as solid *hydrocarbons*. In the sugars the number of atoms of carbon is balanced, as it were, by as much hydrogen and oxygen as would form the same number of atoms of water; hence they are frequently named *carbohydrates*, or *carbhydrates*.

The azotized substances of the body have a still more complex chemical constitution. Even the simplest of them are *quaternary* compounds, containing, besides a large amount of nitrogen or azote, certain proportions of carbon, hydrogen, and oxygen. Some of them are even quinary compounds, containing, in addition, either sulphur, iron, or phosphorus, in some yet unknown state of combination. The percentage composition of these azotized substances, as given in the next page, has been more or less accurately determined; but the atomic constitution of a few of them only, as indicated by the letters and numbers placed between brackets, is well agreed upon. Except keratin, they are all remarkably prone to putrefaction or spontaneous decomposition.

Of the azotized substances of the body, it is found, as is shown in the following table, that albumen, fibrin, and casein have almost exactly the same chemical composition. Each of them, moreover, has a minute quantity of phosphate of lime associated with it. By boiling, and so dissolving, either of these substances in a solution of caustic potash, its sulphur is removed from it; and when the animal substance is reprecipitated in a solid form by acetic acid, its composition is altered only by the loss of sulphur. This desulphurized substance,—the same in character whether obtained from albumen, fibrin, or casein,—was supposed by Mülder to be the true basis of each of these three substances, which differed only, according to this view, in the relative quantities of sulphur which they contained. This common hypothetical base was accordingly named by him *protein* (from ρῶτοςπ, prōtos, first); and the albumen, fibrin, and casein were regarded as *compounds of protein* with sulphur, and were designated *proteinaceous substances.* Protein, however, is an artificial product, the result of a very violent chemical action; and it cannot be admitted as an actual constituent of the body. On this and other grounds, the protein theory is not now generally accepted; and it is considered better to regard albumen, globulin, syntonin, fibrin, and casein, as closely allied bodies, of which albumen is the type, so that they may be called *albuminous* or, better, *albuminoid* substances.

		Carb.	Hydr.	Nitr.	Oxyg.	Sulph.
100 parts Albumen, ...	=	53.8	7.	15.5	22.5	1.2
" Fibrin, ...	=	52.7	7.	15.8	23.4	1.1
" Casein, ...	=	53.8	7.	15.8	22.4	1.
" Gelatin, ...	=	50.3	7.2	18.	24.5	
" Chondrin, ...	=	49.3	6.6	14.4	29.3	.4
" Keratin (hair), . . .	=	51.	6.5	17.	25.	.5
" Hæmatin (blood), . .	=	65.5	5.4	10.4	11.8	6.9 (iron.)
" Black pigment (eye), .	=	57.5	5.9	13.7	22.9	
" Green pigment (bile), .	=	60.2	5.8	8.5	25.9	
" Cerebric Acid (brain), .	=	66.7	10.6	2.3	19.5	.9 (phos.)
" Cholic Acid ($C_{26}H_{43}NO_6$), . .	=	67.1	9.2	3.	20.7	
" Tauro-cholic Acid ($C_{26}H_{45}NO_7S$), .	=	60.6	8.7	2.7	21.8	6.2
" Cholalic Acid ($C_{24}H_{40}O_5$), . . .	=	70.6	9.8	—	19.6	
" Glycocoll ($C_2H_5NO_2$), .	=	32.	6.6	18.7	42.7	
" Taurin ($C_2H_7NO_3S$), .	=	19.2	5.6	11.2	38.4	25.6
" Creatin ($C_4H_9N_3O_2$), .	=	36.7	6.9	32.	24.4	
" Creatinin ($C_4H_7N_3O$), .	=	42.5	6.2	37.2	14.1	
" Sarcin ($C_5H_4N_4O$), . .	=	44.1	3.	41.1	11.8	
" Guanin ($C_5H_5N_5O$), . .	=	39.8	3.3	46.3	10.6	
" Xanthin ($C_5H_4N_4O_2$), .	=	39.4	2.7	36.9	21.	
" Hippuric Acid ($C_9H_9NO_3$), ...	=	60.3	5.	7.8	26.9	
" Uric Acid ($C_5H_4N_4O_3$), .	=	35.7	2.4	33.3	28.6	
" Urea (CH_4N_2O), . . .	=	20.	6.6	46.7	26.7	

As to the other azotized bodies, in the first place, gelatin seems to be a modification of, or derived product from, albumen,—the sulphur being gone, the carbon diminished, and the nitrogen and oxygen increased. Chondrin has a little sulphur still retained in it, and so has keratin. The coloring matters of the blood, the eyeball and the bile, have also the appearance of being derived from albumen,—the carbon being increased, the hydrogen and nitrogen diminished, and, in the case of the hæmatin, an extraordinary addition appearing in the shape of seven per cent. of iron in some unknown state of combination. Cerebric acid is regarded as a slightly azotized fatty substance, which also contains phosphorus; cholic acid is also fatty; both, therefore, contain much carbon and hydrogen. Another fatty acid in the bile (the tauro-cholic) contains in addition a little sulphur. The extractive matters creatin and creatinin, sarcin, xanthin, and others, are mainly distinguished by the large amount of nitrogen they contain. This is also the case with urea and uric acid, both which excretory substances, however, are more highly oxidized, or contain proportionally more oxygen than the preceding substances.

The non-azotized bodies, such as simple fat and sugar, yield, on being decomposed or burnt, carbonic acid (CO_2), and water (H_2O) only, the additional quantities of oxygen required being derived from the atmosphere. By natural decomposition, as already stated, the azotized organic matters yield ammonia (NH_3), which consists of one atom of nitrogen and three atoms of hydrogen: those which contain sulphur (especially albumen), also yield sulphuretted hydrogen gas (H_2S), which is a compound of two atoms of hydrogen, and one atom of sulphur. By destructive heat, these substances yield, besides ammonia, water, and carbonic acid, sulphuric acid (SO_3). Any saline or earthy matter, associated in the tissues with either the azotized or non-azotized substances, is left as *ashes* after the burning.

Finally, then, it appears that the ultimate chemical elements entering into the composition of the body, are those which are indicated in the following table, to which, however, must be added a trace of manganese (probably associated with the iron), and sometimes traces of aluminium, copper, and lead, probably accidental. The percentage proportions of these ultimate elements have been said to be as follow:

Gases.	Oxygen,	72.
	Hydrogen,	9.1
	Nitrogen,	2.5
	Chlorine,	.085
	Fluorine,	.08
Solids.	Carbon,	13.5
	Phosphorus,	1.15
	Calcium,	1.3
	Sulphur,	.1476
	Sodium,	.1
	Potassium,	.026
	Iron,	.01
	Magnesium,	.0012
	Silicon,	.0002
		100.

The entire body, that is, the body with its natural moisture, is composed, therefore, of about eighty-four parts of gaseous chemical elements to sixteen parts of solid elements.

The greater part of the oxygen and hydrogen exists in the state of water, but the dried residue still contains some gaseous as well as solid elements. It will be seen that, setting aside the components of the water, carbon is the most abundant element in the dried tissues, then oxygen, next nitrogen, then hydrogen, and afterwards the other elements as placed in the table.

We have now traced the structure and composition of the lifeless human body; and we find that, at last, in the inevitable decomposition of its various complicated organs, whilst its hydrogen and nitrogen, with part of its oxygen and carbon, are restored to the inorganic world in the shape of *water*, *carbonic acid*, and *ammonia*, the rest of its carbon and oxygen, its chlorine and fluorine, its phosphorus and sulphur, and its metallic bases, calcium, sodium, potassium, magnesium, and iron, with its trace of silicon and manganese, revert to the condition of inorganic *salts* and *earths*, viz., to carbonates, sulphates, and phosphates, chlorides, and fluorides of the above-named saline and earthy bases. Its materials thus literally return to their inorganic state.

In sea-fishes, and in the lower marine animals, iodine and bromine probably are present. Iodine exists in cod's liver oil, and also in marine sponges.

PHYSIOLOGY;

OR,

THE LIVING BODY.

GENERAL PHYSIOLOGY.

VITAL PROPERTIES OF THE TISSUES.

THE animal tissues, the microscopical structure, chemical composition, and physical properties of which have now been described, possess and manifest, *during life*, certain further and peculiar properties, altogether different from those exhibited by inorganic substances, at once distinguishing them from such bodies, and enabling them to perform certain important uses in the living animal body. Hence these properties have been named *vital properties*. Of these vital properties two are special, *i. e.*, are confined each to one elementary animal tissue or substance respectively; whilst a third vital property is general, *i. e.*, is manifested by all the living tissues. The two former properties are *contractility* and *sensibility;* whilst the latter is known under several names, of which we prefer, as a general term, that of the *formative* or *organizing* property.

Vital *contractility* is the power possessed by certain tissues of contracting, or shortening themselves, in one direction. It is especially manifested by the fibres of muscular tissue, and is most probably the source of all intrinsic motion in the living body; for it is possibly even the cause of ciliary motion, and of all the movements in animal protoplasm. It is sometimes named *irritability*, and, more definitely, *muscular irritability:* by Haller it was distinguished as the *vis insita*, or *vis musculosa*.

Sensibility is the special property of the nervous tissues. If taken to represent all the vital properties of nervous substance, in which general sense it is here understood, sensibility is a more complex endowment than the contractility of the muscular tissue. It might be spoken of as the nervous irritability, but a common and more appropriate term for it is the "*excitability*" of the nervous tissues. This peculiar vital property of nervous excitability is manifested both by the nerve-fibres and the nerve-cells. In the former, it appears as *simple excitability*, or the property of receiving impressions from, or being excited by, certain stimuli; whilst, in the latter, it assumes more special forms of reception and reaction, constituting true *sensibility*, to which must be added *volitional* and *excito-motory* or *reflex* power. Moreover, both forms of tissue are able not merely to receive, but also to transmit, the effects of impressions, whilst the nerve-cells especially originate internal actions. That nerve-fibres possess, in a marked degree, the power of conducting the effects of impressions, either inwards to proper receptive or reflective nervous centres, endowed with *special excitabilities*, which are then called into play, or outwards to the muscular organs, which being endowed, as we have seen, with contractility, then contract. That action of the nerve-fibres of certain nerves, which consists in conducting the effects of stimuli to the muscular tissue, and causing it to contract, was named by Haller the *vis nervosa;* and there is reason to believe that the property, by which other nerves conduct the effects of stimuli inwards to the nervous centres, is of precisely the same nature. This power of conducting the effects of impressions, in either direction, may be named *conductility*, or, as has been suggested, *neurility;* whilst the general term excitability must include, not only this conductility, but likewise the power of receiving impressions, possessed by the nerves and nervous centres, and also the special reactions and actions of the latter, whether these be sensorial or motorial.

The general *organizing* or *formative* property is that on which the *development*, *growth*, and *nutrition* or maintenance, of all the animal tissues depend. It is also a complex property, or may, at least in imagination, be supposed to consist of two associated properties. One of these is *purely assimilative*, and enables a tissue to appropriate to itself such external matter as it needs, and to convert it into its own substance, for the purposes of its increase, whilst undergoing development and growth; or for its maintenance during those conditions of waste and renovation, which accompany and follow the exercise or use of the tissue. This purely assimilative or nutritive property is sometimes named the *metabolic* property or *vital affinity*. The second organizing property modifies or controls the direction of the assimilative property, so far as to guide its operation to the production of certain *organic forms*, both in the entire individual, and in the separate organs, parts, tissues, and ultimate structural elements of which it consists. This is the *proper* organizing or *plastic* property, and has been also named the *metamorphic* property. The metabolic or assimilative process is evidently a chemical process of a higher character than ordinary chemical processes; or as it may be termed, a *vito-chemical* process; but the metamorphic or plastic property is purely and absolutely a *vital* process.

Of the three general vital properties just described, the last, or organizing property, is common to plants and animals. An imperfect form of contractility occurs in a few parts of certain plants; but sensibility, or nervous excitability, is quite peculiar to animals.

These vital properties of the animal tissues seem to be, as it were, dormant in the living organism, whether it be a germ, embryo, or adult, unless they are called forth by the action of various agents named *stimuli*. Such stimuli, from their operation being peculiar and essential to living bodies, are sometimes entitled "vital" stimuli; but that term is more appropriately limited to such stimuli as actually originate in living organisms. Speaking generally, the stimuli to life are some external and some internal. The *external* stimuli are either mechanical, physical, or chemical, such as pressure, friction, pricking, or cutting, heat or cold, electricity, light, and various chemical agents. Such stimuli, with the exception of light, if applied to a contractile or muscular tissue, cause it to contract; if applied to the nervous tissues, they rouse their excitability, bring into operation the conductility of the nerve-fibres, and, through them, excite the special sensibilities of different nerve-cells, or, indirectly, induce muscular contractility. In the former case, one result only is produced, whatever be the nature of the stimulus, viz., contraction or motion; in the latter case, the effects differ according to the nature of the external stimulus, or the character of the nervous excitability of particular nerves or nervous centres, *i. e.*, to their susceptibility to react in a peculiar manner in relation to those stimuli. Thus pressure produces the sensation of touch; changes of temperature the sensations of heat and cold; rapid mechanical vibrations, hearing; chemical actions excite taste and smell, and luminous vibrations produce sight. The *internal* stimuli are partly of the same nature as the external stimuli, as *e. g.*, the stimulus of food, which is partly mechanical and partly chemical, and which may produce both motion in contractile tissues and sensation in sensitive tissues. Of the same nature is the internal chemical stimulus of the blood, chiefly due to the oxygen which it absorbs from the air; and, lastly, to this category, also, belongs the physical stimulus of the internal animal heat proper to the individual. The last-named stimuli might be called *vito-physical* and *vito-chemical*. There are other internal stimuli which may more properly be named *vital*, for they are neither mechanical, physical, nor chemical. These are the purely *mental* stimuli, which arise from consciousness and perception, and are either ideational, emotional, or volitional. These, however, also originate, so far as the body is concerned, in peculiar states, conditions or affections of the nervous centres, and in them only; and, as we shall hereafter see, their exercise is always associated with chemical and electrical changes in the nervous molecules, and therefore they present likewise a vito-physical and vito-chemical aspect. The stimuli which act on the body from without, have been characterized as objective, and those which act from within, as subjective stimuli; but, as we shall explain in the chapter on Sensation, in speaking of the so-called objective and subjective sensations, there is a certain confusion in the use of these too much hackneyed and sciolistic phrases.

The external and internal stimuli, mechanical, physical, chemical, and vito-physical, vito-chemical, or vital, also operate on, and excite, the assimilative and plastic property of the tissues. Thus, without external heat, no seed or germ is developed, heat being the so-called "efficient cause" or "motive power," of all germination, development, growth, and nutrition; and certain ranges of temperature are subsequently essential to the excitement and maintenance of all the nutritive processes. Food, water, oxygen, and other chemical agents, are essential to the manifestation of plastic power. Light also exercises a stimulating influence upon this property; and, when the organism is once formed and complete, the internal stimulus of the blood, and that of the animal heat, also excite and support the formative and assimilative processes. Lastly, the purely nervous and mental stimuli, originating in the nervous centres, likewise modify the formative and assimilative processes.

The *uses* of the three so-called vital properties of the animal tissues, may be thus briefly summed up. The use of contractility is to produce all the varieties of independent motion proper to certain parts of the living frame. The use of the excitability and conductility of the nervous tissue, is shown in the control of the movements of the body, both involuntary and voluntary, and in the various forms of sensation, and their consequences, such as emotion, thought, and will. Lastly, the office of the organizing power, *i. e.*, of the conjoined assimilative and plastic powers, is the formation, development, and growth, of all the individual tissues, parts, and organs of the body, and their maintenance in an active living condition.

In that condition, there occurs a ceaseless internal motion and change of material, involving the constant removal of old, or used and disorganized, matter, and the absorption and conversion, the assimilation and organization of new matter, which are the great characteristics of a *living* body. The cessation of these changes constitutes *death.*

Indeed, it is this active condition of all the parts of the body, manifested through the exercise of the various vito-physical, vito-chemical, and vital properties, called into play by external and internal stimuli, which yields a total result known as "*vital action*," or "*life.*" The life of an individual animal is the sum of its various actions, the aggregate of its vital phenomena. "Life is organization in action." (Béclard.) Sometimes, however, the term life has been understood to signify "the mode of action" of living bodies. Again, it is also frequently employed to indicate a special agent, principle, or entity, which is considered to be the source, or cause, of all the vital properties and actions; but this use of the word is, perhaps, better avoided. The term "vitality" has a somewhat similar signification; but it might rather be restricted to the power or capacity of living. The expression "*vital force*" indicates a still further step made by our minds in the endeavor to define the causation of vital phenomena. The use of the term "force," in this sense, is hardly to be avoided in physiological discussions any more than that of the "force" of gravitation in physical explanations; but it is, unfortunately, employed in totally dissimilar senses. A vital "force" is as unknown to us as the force which causes gravitation or attraction; and we can only infer or assume its existence, as the cause of certain properties in living things: we cannot know it. Besides this, we use the term "force" very differently, when we speak of the vital force of the whole system, in relation to health or disease, or, separately, of the muscular, nervous, and plastic forces, or of the force of the arm, the heart, or the thorax, or of the secreting force of a gland, or of the solvent or digestive force of the gastric juice. We shall hereafter see reason to regard most of the so-called forces, thus assumed to operate in the body, as modifications of that common force which, in the inorganic world, is supposed to act in various modes, sometimes by attraction—as in cohesion and gravitation—the latter being often a cause of visible motion; sometimes as an invisible motion, causing heat; at other times as light, or electricity, or chemical affinity; all which phenomena are supposed to be due to correlated manifestations of one and the same universal force pervading all matter. In living animal bodies, we need no longer assume the presence of so many distinct and peculiar forces as were formerly admitted. As we have seen, all the vital actions of animals may be referred to three primary properties,—contractility, nervous excitability, and the organizing property. But even for the explanation of these, we do not require to assume the existence of three corresponding and purely vital forces, entirely unrelated to the supposed common force of nature; for the contractility of muscle, the simple excitability and conductility of the nerve-substance, and the assimilative or metabolic affinity of the tissues, though truly named vital properties, as being only exhibited by living bodies, may all depend on, or rather may be merely modifications or special manifestations, within the living organism, of the common force of nature, acting either mechanically, osmotically, electrically, or chemically. Even the higher excitability of the nervous cells, manifested in actual sensation and its mental consequences, does not, as already pointed out, escape association with such corporeal changes as may well be regarded as dependent on vito-physical and vito-chemical modes of action of that common force. But there remains a mystery in this manifestation of *feeling* and *consciousness* in connection with matter, even when contemplated in the case of animals, which no physical hypothesis has yet cleared up. Moreover, the vital phenomena dependent on the higher organizing or metamorphic property, cannot at present be so explained; nor is it easy to conceive the possibility of so explaining them, by reference merely to mutations of the universal physical force, which undoubtedly subserves, and is essential to, their manifestation.

The formation of a fluid or solid mass of albuminoid protoplasm, *may* be conceived to be due to a vito-chemical process, and its maintenance to vito-chemical changes; but the *shaping* of this to an organic form, whether a nucleus, a naked nucleated cell or gymnoplast, or a perfect cell with envelope or cystoplast, or the multiplication, modification, and adhesion of these in definite order, manner, and connection, to form a complex animal or vegetable, implies the presence of some further controlling power. There would seem, indeed, to be some special force in animals and plants, by which the tissues, parts, and organs are evolved in determinate shape, size, and position, and are definitely endowed with their ordinary properties; and by which, moreover, entire organisms are developed in apparently endless variation, according to the distinctions of kingdoms, classes, orders, genera, species, race, sex, and individuality. These remarkable phenomena are accordingly said to imply the presence of a guiding, controlling, and dictating force, modified in innumerable ways by external and internal conditions, transmissible from generation to generation, and certainly distinct from, though co-operating with, the common physical force of nature. This is truly a "*vital*" force,—a force properly called "organic,"—on which the very existence of both animal and vegetable organisms depends. It is this force, also known as the "germ force," which develops and maintains the body and all its parts, with their respective vito-physical, vito-chemical, and other so-called vital properties, and so imparts to them even their very highest endowments.

GENERAL VIEW OF THE ANIMAL FUNCTIONS.

The life of man, and of the higher animals, consists ultimately, as already said, in the manifestation of the various properties of the structural elements of the different tissues and fluids; but, in its more obvious effects, it is manifested in certain special acts, which are known as *functions*, performed by the instrumentality of the parts named *organs*. Life, as we have seen, is organization in action. These functions are the endowments of the organs, just as the vital properties are the endowments of the tissues; and, as most organs are constructed of many tissues, the functions of such parts are necessarily more complex processes than the fundamental actions of the tissues.

The functions of animals are divided into two principal groups, named respectively, the *animal* and the *vegetative* functions, the former being essentially limited to animal organisms, the latter being common to both animals and vegetables.

In contemplating the phenomena presented to our notice by one of the higher animals, *e. g.*, by the dog, or rabbit, the dissection of which latter animal has been previously described (page 39), the most obvious fact is their power of moving from place to place, and of performing various other actions, prehensile, offensive, defensive, and so on. These several movements are ascribed to the common function of *motion*, including the acts of locomotion, prehension, and others, performed by means of the so-called *passive organs* of motion, the *bones* and *joints*, and by the *active organs* of motion, viz., the *muscles* and their *dependencies*.

But the movements of the dog are neither desultory nor irregular, but are evidently directed to certain ends and objects desired by, or useful to, it. For this purpose, the animal must *feel*, using that term in its widest sense; it must also be able to *perceive*, and, to a certain extent, to *reason* upon, the results of certain external influences, to *desire* to obtain this or to avoid that; and it must possess the power of *will*, issuing in the *voluntary control* over the muscles, the immediately active organs of motion. Besides this, it is endowed with an *involuntary regulating power* over certain movements, which tend to the preservation of its various organs from injury, or aid in the performance of certain important vegetative functions, such as deglutition and respiration. In these various states and acts, the animal exercises the functions of *sensation*, the *psychical functions*, and those of the *regulation* of the *muscular movements*, all of which are accomplished through the agency of the nervous apparatus, consisting of the *brain* and *spinal cord*, of certain *ganglia*, and of the numerous connected cords formed by the *nerves*. In the exercise of the various kinds of sensation, the animal feels, tastes, smells, hears, and sees, by means of the vibrissæ, tongue, nose, ears, and eyes, *organs* of *special sense*, furnished with appendages for their protection and more efficient use, and destined to receive impressions made by various external stimuli, the effects of which are transmitted by special nerves to the great organ of sensation, the brain. In this organ, also, not only consciousness of the sensations, but all other psychical phenomena, have their corporeal seat; such as perception of the outward causes of the sensations, ideas, emotions, desires, reasoning processes, and will, the stimuli or mandates of all which latter proceed from the brain to the muscles, destined to perform the necessary ideational, emotional, or voluntary acts. In other cases, stimuli produce impressions on the nerves, which are conveyed to the spinal cord, or to its extension upwards into the head, named the "medulla oblongata," and do not induce sensation, but are *reflected* outwards involuntarily along other nerves to particular muscles, which then contract and perform the necessary movements. There exist accordingly, in the animal organism, *sensory nerves* and *sensorial nervous centres*, *motor nerves* and *motorial nervous centres;* and there are also found nervous centres concerned in the reflected or *reflex* motor actions of the body.

These mixed motor, sensory, and psychical functions, which constitute the so-called proper *animal* functions, cannot be performed continuously without cessation. The animal sooner or later becomes exhausted in regard to them; the brain becomes weary and the muscles fatigued. Rest is indispensable. These functions are for a time suspended, and the condition known as sleep occurs, which, when perfect, is accompanied by the temporary suspension of all these animal functions—motor, sensory, and psychical. But sleep is insufficient of itself permanently to restore animal activity. In the exercise of the muscular and nervous systems, these organs undergo a destruction or waste of their component molecules. During every interval of rest, as well as during sleep, they are renovated by materials derived from the common nutrient circulating fluid, the blood. But the blood itself, in thus contributing to restore the wasted nervous and muscular organs, itself becomes impoverished. Under these circumstances, it may, for a time, draw material from one part of the body to sustain, as long as it can, another part,—the more passive organs of the frame yielding nutriment to those more actively endowed. But the waste still goes on in proportion as action is renewed; fatigue again ensues; rest and sleep are once more indispensable. The animal day by day would emaciate, get weaker, and ultimately die of inanition. To prevent this, new material must be added to the blood from the outer world. This material consists of food, drink, and air; and to impel the animal to seek them, the *special feelings of hunger and thirst* arise within it. Besides this, during the waste of the active tissues in the proper animal functions, the products of the decomposition of the wasted substance of the muscular and nervous systems, and of their dependencies, are drawn into the current of the circulation, and render the blood more or less impure. Its impurities, so derived, must be thrown off; otherwise life would be extinguished, not by inanition, but by an act of self-poisoning, either slow or rapid, according to the nature and quantity of the impurity so retained in the circulating fluid.

Hence to maintain the balance between the necessary waste and renovation of the body, to preserve the purity of the blood and the integrity of the animal organs, and so render possible the due exercise of the proper animal functions, certain other, and most complex, functions require accordingly to be regularly performed. These, which form one subdivision of the group of *vegetative* functions, are named the *nutritive functions.*

The animal, constrained to seek for food, seizes it by prehensile movements, and introduces it into the interior of its body, exercising thus the function of *prehension* of food. Such food is, however, unfitted, without due preparation, for actual entrance into the substance or tissues of the animal, and is therefore subjected to certain special processes, included in the general function of *digestion*, performed by the *alimentary canal* and *its appendages.* First, the food, at least in the higher animals and in man, requires to be bruised or comminuted by the process of *mastication* performed by the *teeth*, *jaws*, and *muscles*, concerned in this act, aided by the *tongue* and *cheeks.* During this reduction of the food, another process is necessary, especially when the food is dry; and that is, its admixture with a large quantity of fluid matter, named the *saliva*, which is formed by the salivary glands, and by aid of which the mass of food is rendered soft enough to be swallowed, while certain of its ingredients are subjected even to chemical change. This constitutes the process of *insalivation.* The *swallowing* of the food, which is named the act of *deglutition*, is performed by aid of the *tongue*, the part called the *fauces*, the *pharynx* or back of the throat, and the *œsophagus* or *gullet.* From the lower end of the gullet, the masticated and insalivated food is propelled into the *stomach*, where it undergoes *gastric digestion* or *digestion proper*, under the agency of the *gastric juice*, which acts chemically on certain portions of the food, and aids in its solution, performing thus the process of *chymification.* By certain movements of the stomach, the softened portion of the food, now named the *chyme*, is urged onwards into the *small intestine*, at the upper part of which it becomes admixed with the *bile* formed by the *liver*, and with the *pancreatic juice* yielded by the *pancreas.* These fluids continue the chemical processes of change and solution already commenced. It is also blended with the so-called *intestinal juice.* After this, the pulpy mixture is fitted for the next great vegetative function, characteristic of all organized bodies, viz., the function of *absorption*, by means of which, the fluid and dissolved parts of the food and drink at length enter into the substance of the living animal, and ultimately gain access to the blood. This absorptive process is accomplished, partly by means of the *bloodvessels* of the stomach and small intestine, and partly by the agency of the special *absorbent vessels* known as the *lacteals*. These, after passing through the *absorbent glands*, which elaborate the fluid, conveyed through them, at last end in the chief absorbent trunk, named the *thoracic duct*, which then pours its contents into the great veins at the root of the neck. The part of the dissolved nutrient matters which enters the absorbents of the small intestine consists of an opaque white *fluid*, called the *chyle;* and the formation of this fluid is termed the process of *chylification*. In this way, partly directly and partly indirectly, the nutrient substances of the food, dissolved and modified by the digestive processes, enter the bloodvessels, and renew the materials of the blood. The unabsorbed residue of the food and digestive juices, gradually passes from the small into the *large intestine*, in which, by a sort of *secondary* or *continued digestive* process, any remaining nutritive matter is almost entirely taken up from it. The final residue, including certain products of decomposition, and other substances thrown off from the system by the liver and the lining membrane of the intestines, forms the solid excreta or egesta, which are removed from the body by the process of *defœcation*.

The blood, thus nourished by what is termed the *primary process of assimilation*, is conveyed through every part of the body, by means of the *heart*, the arteries, the capillaries, and the veins. It is propelled from the heart through the arteries, passes from them into the capillaries, and returns thence to the heart through the veins. Thus the function of *circulation* is performed, the parts just named constituting its organs. In the higher animals, and in man, the circulation is double, or consists of two circular currents, each proceeding from the heart, and returning to that organ again; one, passing through the body, is named the *systemic*, the other, through the lungs, the *pulmonary circulation*. In the former, a pure or arterial blood proceeds from the heart, whilst an impure or venous blood returns to it: in the latter, the blood issuing from the heart is venous or impure, whilst it returns arterialized or pure.

We have now arrived at the point at which the waste of the organs concerned in the animal functions of sensation, mental action, and motion, may be repaired by the great and common function of *nutrition proper*, *nutritive secretion*, or *secondary assimilation*. To accomplish this, new materials in a dissolved state, derived from the blood, percolate through the fine walls of the capillary vessels, and constitute what is called the *nutritive plasma*. From this common transparent colorless fluid plasma, which moistens every tissue of the body, the elementary tissues of each organ appropriate, by their assimilative property, such materials as are needed for their renovation, or the restoration of their wasted molecules; and, under the influence of their plastic property, deposit new material, molecule by molecule, in the place of the disintegrated or wasted substance, so as to preserve unchanged, the characteristic elementary structure of the tissue, and the general form of the organ so nourished. The residual plasma passes, it is supposed, together with the products of the wasted tissue, back into the blood again, in part, directly, through the walls of the capillaries and finest veins, but also, and chiefly, through the general *absorbent vessels*, which resemble the lacteals already mentioned, but which are named *lymphatics*, because they here carry a clear fluid or *lymph*. Should accident or disease still further impair the integrity of an organ by bruising, cutting, or by inflammatory processes, the nutritive function is exercised, in a special manner, for the *reparation* of the injured part, and sometimes even for the restoration or *reproduction* of lost parts. Nutrition includes, therefore, the processes or functions of reparation and local reproduction. Lastly, parts which are destined to be removed, such as the fangs of the milk teeth, and the materials of the growing bones; or morbid deposits, such as blood which has escaped from the vessels into the tissues; and inflammatory products,—are likewise absorbed back into the blood, by the act of *nutritive absorption*, which is performed jointly by the capillaries and the lymphatics.

But, besides all this, there is included in the nutritive function, the conveyance of a so-called *stimulating* substance to those two remarkable tissues of the animal body, the muscular and the nervous tissues, both of which require, for the performance of their proper functions, not only new material to replace that which is destroyed or disintegrated by use, but likewise the presence of arterial blood, for the maintenance of their peculiar vital endowments: such blood operates chiefly by virtue of the large quantity of oxygen which it contains. In supplying the requisite materials for the nutrition and stimulation of the tissues, all of which have their characteristic chemical composition, in receiving back the residual nutrient substance, and in furnishing the materials for another important nutritive function, named *secretion*, to be presently described, the blood itself becomes not only exhausted as regards the quantity of its ingredients, but necessarily modified as regards their quality; and hence certain special elaborative processes are continually going on, for the purpose of securing its own nutrition; these constitute the functions of *sanguification*. This is accomplished partly by the absorption of new matter entering through the lacteals and the absorbent glands, already mentioned, and also it is believed by the agency of certain organs named vascular glands or blood glands, such as the *spleen*, the *supra-renal bodies*, the *thyroid body*, and the *thymus gland*, and the so-called *Peyer's glands* and *solitary glands* of the intestinal canal, all of which appear to assist in the elaboration of special materials for the blood.

We have seen that in order to render the nutrient substances contained in the food soluble, and fitted for absorption, certain animal fluids or juices are employed in the process of digestion, such as saliva, gastric juice, bile, pancreatic fluid, and the intestinal juice. These special fluids require each a special organ in the body for its preparation, named a *gland*. Moreover, they are prepared within these glands, from the fluid plasma of the blood poured out through the coats of the capillaries. The general process by which they are thus separated from the blood, is known as *secretion*, and the glands are called *secreting glands*. The process of secretion is closely allied to that of nutrition; in the former, the fluid material elaborated from the blood, escapes on to the external or internal surfaces of the body; whilst in the latter it is retained within the body in the more solid form of tissue. Besides those just mentioned as associated with the alimentary canal, other glands, such as the *lachrymal* and *mammary* glands, exist, the secretions of which fulfil special offices in the economy. In addition to the continued alteration of the blood produced by its subservience to so great a variety of nutritive processes, by the loss of stimulating material conveyed to the muscular and nervous tissues, by the varied process of secretion, and by the operations connected with nutritive absorption and sanguification, the blood, as we have seen, is made the vehicle for the reception of the waste material of the disintegrated tissues, which, dissolved in the residual plasma exuded amongst their ultimate structural elements, is, at least in part, reabsorbed into the circulating current. These effete matters, if permitted to accumulate in the blood, poison it, and render it unfit for the stimulation of the nervous and muscular tissues, for the proper nutrition of the tissues generally, and for the purposes of healthy secretion. Accordingly, another function is added to the nutritive vegetative functions of the animal economy, named *excretion*, by means of which the blood is enabled to get rid of these effete materials through the action of certain emunctory organs, named the *excreting glands*, of which the chief are the *kidneys*, the *cutaneous sweat glands*, and the *lungs*. The liver and the intestinal mucous membrane, moreover, also assist in this excretory function. By means of the urinary, cutaneous, and pulmonary excretions, and of the solid excreta from the alimentary canal, all the products of the decomposition of the tissues are regularly removed; and as these tissues are as constantly renovated from the blood, and the blood itself from the food, there exists a balance in the nutritive actions of the living economy, and a correspondence between the daily quantity of food consumed, and the daily amount of the vito-chemical nutritive changes occurring in the body.

Of the various excretory processes, there is one, viz., the elimination of the carbonic acid from the lungs, which is distinguished from the rest by its being associated with another process equally essential to animal life, viz., the introduction of oxygen into the blood and tissues of the living animal. This is accomplished in *breathing*, the characteristic act of that most important function, *respiration*. After the reception of food into the body, all the ensuing nutritive processes which we have described above, are hidden or concealed from observation; but the process of breathing is one which is externally manifested. The animal under observation, indeed, is seen to breathe; the sides of its thorax expand and contract, and it alternately draws in and expels air from the interior of its frame. The air enters through the *nostrils*, and also sometimes through the *mouth*, into the *throat* or *pharynx*, and thence through the *larynx*, *windpipe* and its subdivisions into the *lungs*, and then it is again expelled from those organs through the same *air-passages*. The former act is called *inspiration*, the latter *expiration*. The air which escapes from the lungs has not the same chemical composition as when it entered them; for, within those organs, it comes into very near proximity with the blood in the capillaries of that part of the circulation named, as before mentioned, the pulmonary circulation; and there an important interchange of certain gases takes place, through the coats of the pulmonary capillaries, between the blood and the inspired air. The air receives, besides moisture, a certain quantity of *carbonic acid*, an excreted product from the impure or venous blood. Thus the lungs become important excretory organs, so important that the arrest of respiration is speedily followed by death. But more than this, the inspired air imparts to the blood a like quantity of *oxygen*, which converts the venous or impure blood, brought from the body through the systemic circulation to the heart and thence propelled through the pulmonary circulation to the lungs, into pure or arterial blood, which goes back to the heart, and is thence again propelled into the systemic vessels of the whole body. The air taken into the lungs is therefore the source of the oxygen of the arterial blood, which nourishes the whole frame, and especially stimulates the muscular and nervous tissues, and so maintains the proper animal functions. This oxygen, moreover, is the main agent, as it would seem, in the disintegration of those two tissues; and the chemical changes effected by its union with their molecules, are intimately associated with the exercise of their special properties of contractility and excitability—so much so, that these properties cannot be manifested without chemical change or *oxidation*. The chemical work thus performed is probably, as we shall see, truly correlated with the *motor* or *mechanical work*, *i. e.*, with the contractile power of the muscles, and also with the more recondite *nervous action;* partly, also, it is transformed into *animal electricity* in these two tissues; and lastly, the oxygen of the air, in producing these chemical changes within the body, all more or less stages of oxidation, likewise produces, as in cases of ordinary combustion, an *elevation of temperature* in the animal frame. Respiration is therefore the functional source of *animal heat*, an important use of this function in the economy, being to produce such heat. In the warm-blooded animals, however, the oxidation of the tissues only, is insufficient to produce an amount of heat adequate to maintain the other functions of their economy, whether animal or vegetative; and hence, such animals take in their food certain additional materials, besides those used for the nutrition of the tissues—materials which merely enter the blood, and therein become oxidated or burnt, for the purpose of producing the required additional amount of heat. Unless, therefore, the animal here supposed to be under observation, be supplied with fat as well as flesh, its activity is lessened, its health is impaired, and its body seriously emaciated.

The entire series of vegetative functions, which we have now examined, viz., digestion, absorption, circulation, nutrition, sanguification, secretion, excretion, and respiration, are named, as we have seen, the *nutritive vegetative functions*, because they are concerned especially in the maintenance and support of the body of the individual animal. They supply the large and constant wants of the proper animal organs of motion and sensation, but their healthy performance demands that their own organs should likewise be duly nourished. Moreover, these organs themselves contain both motor and sensory parts, *i. e.*, muscular and nervous tissues. The former are exemplified in the muscles of mastication and deglutition, the muscular coats of the alimentary canal, the walls of the heart, the muscular tunic of the arteries and of the ducts of glands, the respiratory muscles, and the muscular fibres of the larynx and air-tubes. The latter consist of various nerves and nervous centres, especially of the so-called *sympathetic nervous cords* and ganglia, hence named the *organic nervous system.* But even the *animal nervous system*, in its various healthy and morbid states, has most important influences upon all the nutritive vegetative functions, aiding or interfering with those of digestion, nutrition, secretion, and the rest.

The nutritive vegetative functions begin, with the exception of digestion, to be manifested at the very commencement of individual life, and they continue through the whole period of existence, from youth, through the adult state, to old age. But the life of the individual is limited, and to avoid the extinction of race, which would otherwise follow such limitation, provision is made for the continuance of the species. Hence in both plants and animals, an additional vegetative function is met with, by means of which, through the evolution and development of germs, gemmules, or ova, new individuals are successively formed from previously existing parents, generation after generation. This, the last function we have to mention, is the *reproductive vegetative function*, in which are included the phenomena of *development and growth.*

The following table will serve not only to give a general view of the different functions, but also to indicate the order in which they are hereafter described.

The Functions of Living Animals.

ANIMAL FUNCTIONS	Motion. Sensation, regulation of movement, and the higher psychical functions.
VEGETATIVE FUNCTIONS:	
Nutritive, . .	Digestion: Mastication, Insalivation, Deglutition, Digestion proper, or Chymification. Absorption; Chylification. Circulation. Nutrition and Reparation. Sanguification. Secretion. Excretion. Respiration; Production of Heat, Motion, and Electricity.
Reproductive, .	Generation. Development and Growth.

RELATIONS OF MAN WITH EXTERNAL NATURE.

In the preceding pages, man's relations with both inorganic, and organic or organized, bodies, whether vegetable or animal, have been fully illustrated. With the inorganic kingdom of nature, man is related, as we have seen, both in regard to the matter which composes, and to the forces which operate within, his frame. As regards the vegetable and animal kingdoms, he is related not only materially, as implied by his dependence upon them for food, clothing, and protection, but with animals, at least, he is both socially and morally connected, as indicated by the employment of those creatures for his use, and by the ties established between himself and them in their domesticated condition.

To the physiologist, however, there are other and nearer relations of special interest, viz., *zoological* relations, as between man and animals only; *biological* relations, as between man and organized bodies generally, whether animal or vegetable; and, lastly, *physical* and *chemical* relations, as between him and the inorganic world. These last-named relations are included in those which exist between organized and unorganized bodies generally. Each of these three kinds of relation requires to be separately examined.

RELATIONS OF MAN WITH ANIMALS.

The zoological relations of man with the animals disclose points of resemblance and of difference between them, exhibited in both structural and functional peculiarities. Modern zoology is founded on what might be termed *zoological anatomy*, of which *human* and *comparative anatomy* are merely branches, inseparably connected, mutually explaining and assisting each other, and leading the mind to wider views of structure, to the laws of analogy and homology established by so-called philosophical or transcendental anatomy, and also to strictly scientific, because truly natural, systems of classification. So likewise, there is a *zoological physiology*, according to which, the modern physiologist, following the example of the anatomist in regard to structure, endeavors to trace a given function through its various degrees of complexity, down to its simplest, and therefore most essential expression. Thus it is, he follows the various sensory endowments of man and the higher animals, as exhibited in the phenomena of the special senses, downwards through the animal scale, observes them becoming fewer and simpler, and at last finds, in some lowly organized animal, common sensation alone present, and thus arrives at the simplest expression of sensibility, viz., mere nervous excitability; in other words, he traces the specialized functions of an organ gradually downwards, till it is reduced merely to the vital property of a tissue. So again, tracing downwards the function of absorption, he speedily meets with animals destitute of special lymphatic or lacteal vessels, and in which, therefore, vascular absorption and circulation are functions performed by the same set of vessels. In like manner, the function of circulation itself becomes more and more simplified, and finally disappears in animals which are destitute of vessels containing a common nutritive fluid. If he turns to digestion, he discovers some animals destitute of digestive glands, others possessing no distinct alimentary canal separate from the general cavity of their body; and lastly, others which are even destitute of a body-cavity. In the last case, nutrition is accomplished by the direct application of the surface of the animal to its food, and by the simple process of direct absorption into its substance. Viewed in this manner, the function of digestion is seen to be reduced to the phenomena of solution and absorption; whilst together with absorption, sanguification and circulation, which are subsidiary functions, it resolves itself into one common function, viz., nutrition. This, indeed, is the simplest expression of all the nutritive functions, and is fundamentally represented by the conjoined assimilative and plastic vital property of the simplest organized tissue, or the simplest form of independent animal life. Lastly, if we trace back the secretive function, we find that a complex organ, like the liver of man and the higher animals, is, in the lower ones, represented by a cluster of follicles, by a single follicle, or by a group of nucleated cells upon the surface of a membrane; and hence we perceive that the essential character of the function of secretion, consists in a modification of the same common property of nutrition, which is named nutritive secretion; and so on of other functions.

To trace these points of comparison, both of structure and of function, between man and animals, frequent reference will have hereafter to be made to facts and details, which will be easier of comprehension, if we first take a general view of the animal kingdom. Motives of utility, and want of space, necessitate the selection and employment of one system of classification only; and preference is here given to the arrangement proposed by Professor Huxley in his *Elements of Comparative Anatomy*, which, besides containing original suggestions, incorporates the improvements of the modern German school.

Outlines of the Animal Kingdom.

The dependence of the classification of animals on their internal structure is fully illustrated in the Cuvierian system, which forms the foundation of all modern arrangements; it has, however, undergone modification, through the further application of the anatomical method, and more extended inquiries into the structure of many of the lower animals, which from want of means or of opportunity of investigation, were but imperfectly known to Cuvier. In his great contribution to comparative anatomy and zoology (*Le Regne Animal*) he divided the entire animal kingdom into four subdivisions, named *subkingdoms.* These subkingdoms were composed of nineteen primary subdivisions named *classes*, which were further broken up into seventy-seven *orders*, and these again into further groups, ultimately separated into *genera* and *species.*

Cuvierian Arrangement.

1. VERTEBRATA.

Mammalia.
Aves.
Reptilia.
Pisces.

2. MOLLUSCA.

Cephalopoda.
Pteropoda.
Gasteropoda.
Acephala.
Brachiopoda.
Cirrhopoda.

3. ARTICULATA.

Insecta.
Arachnida.
Crustacea.
Annelida.

4. *RADIATA.*

Echinodermata.
Intestina.
Acalepha.
Polypi.
Infusoria.

The preceding table is so arranged as to show at a glance the four Cuvierian subkingdoms and their respective classes. The Radiate subkingdom is now scattered. As regards the classes, the names printed in italics indicate those which have been since subjected to various degrees of change, either having received additions, been broken up into distinct classes, transferred to others already existing, or even placed in entirely new subkingdoms.

The primary divisions or subkingdoms of Cuvier are not founded on any one common principle, but each is based upon a separate mode of distinction or definition. Thus the *Vertebrate* subkingdom, including, as seen above, the classes of Mammals, Birds, Reptiles, and Fishes, has for its basis a point of internal structure, viz., the possession of a vertebral column or back-bone, forming the fundamental part of the internal skeleton. The subkingdom *Mollusca* contains the classes Cephalopoda, illustrated by the cuttle-fishes and nautilus; Pteropoda, or sea-butterflies, marine animals, represented by the clio and others; Gasteropoda, consisting of snails, slugs, whelks, periwinkles, limpets, and other marine animals with univalved shells, as well as numerous sea-slugs and other allied shell-less species; the class Acephala, or headless molluscs, including the Testaceous bivalved oysters, mussels, cockles, scallops, and others, with the so-called simple and compound Tunicated marine animals; the Brachiopods, also bivalved marine animals; and lastly, the Cirrhopods or barnacles. The Mollusca are so named from an external general character which is common to them all, though less marked in the barnacles, viz., a soft fleshy kind of body. The *Articulate* subkingdom comprehends Insecta, with the myriopods, or centipedes, and millipedes; Arachnida, or spiders; Crustacea, including crabs, lobsters, shrimps, and many smaller crustaceans; and all the Annelida, such as worms and leeches. It is based also on a general external character, viz., the more or less jointed or divided form of the body and limbs where these exist. Lastly, the *Radiate* subkingdom is founded also on an external character, derived from the general radiated form of the body, or of the appendages situated around the mouth or oral aperture of the body-cavity: it includes the Star-fishes, the Intestinal Worms, the Medusæ or sea-nettles, the various Polyp-shaped animals, such as the sea-anemones, the gelatinous polyps resembling the little fresh-water hydra, and also the coral-forming polyps; and finally the class of Infusorial animalcules, including the Rotiferous or wheel animalcules.

The definitions of the classes were for the most part, and, indeed, always, so far as his knowledge extended, founded by Cuvier, on anatomical characters. Imperfect knowledge led him, however, to an imperfect separation or grouping of these in certain instances. The results of modern investigations are embodied in the following table of the subkingdoms and classes, which exhibits the classification adopted by Huxley, with the single exception of placing the Infusoria as a class amongst the Protozoa, instead of ranking them as a more important independent group. The subkingdoms, seven in number, and the classes, twenty-six in number, are arranged on a similar plan to that already adopted in regard to the Cuvierian system, so that the two may be readily compared.

Modern Arrangement.

1. VERTEBRATA.
   - Mammalia.
   - Aves.
   - Reptilia.
   - Amphibia.
   - Pisces.

2. MOLLUSCA.
   - Cephalopoda.
   - Pteropoda.
   - Pulmogasteropoda.
   - Branchiogasteropoda.
   - Lamellibranchiata.

3. MOLLUSCOIDA.
   - Ascidioida.
   - Brachiopoda.
   - Polyzoa.

4. ANNULOSA.
   - Insecta.
   - Myriopoda.
   - Arachnida.
   - Crustacea.
   - Annelida.

5. ANNULOIDA.
   - Scolecida.
   - Echinodermata.

6. CŒLENTERATA.
   - Actinozoa.
   - Hydrozoa.

7. PROTOZOA.
   - Infusoria.
   - Spongida.
   - Rhizopoda.
   - Gregarinida.

In explaining the advance of zoological knowledge as exhibited in these two tables, attention may first be directed to the changes which have been made in the smaller subdivisions or *classes*. The vertebrate classes have suffered the least alteration—the class Reptilia having been merely divided into the proper Reptiles, such as the snakes, turtles, and lizards; and the Batrachia or Amphibia, represented by the frogs and salamanders. Amongst the Mollusca, the class of Gasteropods has been divided into those which breathe by lungs, and those which respire by gills, *i. e.*, into the Pulmo- and Branchio-gasteropoda. The class Acephala, which included the testaceous and tunicated orders of Cuvier, are subdivided into two corresponding classes, named the Lamellibranchiata and the Ascidioida, the latter of which has been placed in a new subkingdom. The class Brachiopoda has also undergone a similar transposition. The class Cirrhopoda, or barnacles, has been transferred as an order to the Crustacea, belonging to another, the Annulose, subkingdom. Of the Articulate classes, one order amongst the insects, named the Myriopoda, is separated from them to form a distinct class; whilst, as already mentioned, the class Crustacea is reinforced by the Cirrhopods. The Radiate classes have undergone the most notable changes, some of them having been much divided, and all rearranged, in other or new subkingdoms. The Echinodermata are otherwise unchanged. The Intestina are associated with certain minute marine worms, and with the rotiferous animalcules from Cuvier's Infusoria, to form a class named Scolecida, placed next below the true worms or Annelida. The Acalepha are made to form part of the new class Hydrozoa. The Polypi are split up and separated in three directions; the order of coralline polyps form the class Polyzoa (sometimes named the Bryozoa); the order Actinia or sea-anemones becomes the class Actinozoa; whilst the order of gelatinous polyps, represented by the hydra, is united with the Acalepha in the class Hydrozoa. Lastly, of the Infusoria of Cuvier, one order, the Rotifera, passes upwards to join, as already mentioned, the Scolecida; whilst the others form the present Infusoria, after discarding certain algaceous vegetable organisms; finally, certain remaining lowly organized animal bodies constitute the new classes Spongida, Rhizopoda, and Gregarinida.

Such being the modifications in those carefully defined groups which constitute the classes of the animal kingdom, we may now direct attention to the resulting changes in the larger groups or *subkingdoms*. The Vertebrate subkingdom remains intact. The Mollusca of Cuvier, diminished by the Cirrhopods, which pass into the Crustacea of another subkingdom, and increased by the Polyzoa, the radiate coralline polyps of Cuvier, present the same general limits as the two subkingdoms, Mollusca and Molluscoida, of the new arrangement, the line of partition between these latter being drawn between the Lamellibranchiata and Ascidioida, *i. e.*, through the centre of the Acephalous Molluscs of Cuvier. The Articulate subkingdom of the French zoologist remains undivided, as the Annulosa, reinforced only by the Cirrhopods, which, as just stated, are now included in the Crustacea. The Radiate subkingdom, corresponding, it may be remarked, with the so-called Zoophytes of many writers, disappears; for its classes are completely broken up and distributed into other or new subkingdoms. Thus, the coralline polyps are transferred to the new subkingdom Molluscoida, and form the lowest Molluscoid class. The new subkingdom Annuloida includes the Echinodermata, with the Intestina and rotiferous order of the Infusoria, the two latter being joined under the name Scolecida. The new subkingdom, named Cœlenterata, comprehends a second group of the polypi, namely, the Actinia, under the title Actinozoa, and also the gelatinous polypi, which, with the Acalepha, form the Hydrozoa. Lastly, the new subkingdom Protozoa includes the Infusoria, with the exception of the Rotifera, which ascend to the Annuloid subkingdom, and also the three lowest new classes, the Spongida, Rhizopoda, and Gregarinida.

The preceding changes are due to the labors of many zoologists. Thus, Carus suggested the term Protozoa, whilst Von Siebold and his followers separated that group into a distinct subkingdom. The Cœlenterate subkingdom and its limits were suggested and defined by Frey and Leuckart. The Molluscoid and Annuloid subkingdoms owe their origin to Milne-Edwards and Huxley, the coralline polyps, or Polyzoa, especially, having been placed in their new position owing to the researches of the former naturalist. The Cirrhopods were long since transferred to the Crustacea by Grant; and the Intestina have, by many authors, been removed to the neighborhood of the true worms. With regard to the worms, some zoologists, as, *e. g.*, Gegenbauer, have even placed them in a distinct subkingdom named Vermes; whilst the Echinodermata have also received similar treatment. Even the Infusoria, as already mentioned, have been separated from the other Protozoa as if forming a group of higher importance than a mere class (Huxley). The general relations between the *subkingdoms* of the Cuvierian and of the modified arrangement here adopted may be expressed by the following schemes:

Cuvierian Arrangement.

VERTEBRATA

MOLLUSCA ARTICULATA

RADIATA

Modern Arrangement.

VERTEBRATA

MOLLUSCA ANNULOSA

MOLLUSCOIDA ANNULOIDA

CŒLENTERATA

PROTOZOA

General Characters of the Subkingdoms.

Vertebrata. The vertebrate animals are distinguished by the possession of an internal skeleton, the central part of which, the back-bone, forms a longitudinal bony or cartilaginous axis, usually divided into segments called *vertebræ*, the entire axis being named the *vertebral column;* anteriorly, this internal skeleton is expanded into the *cranium;* laterally, the vertebral column frequently presents symmetrical pieces, named *ribs;* and, besides these, there may exist two or four, but never a greater number, of larger lateral appendages, placed symmetrically on each side, and named *limbs.* Within the vertebral column, and (supposing this to be placed horizontally), above the more solid part formed by the so-called bodies of the vertebræ, is an elongated cavity continuous in front with the cranial cavity, and named the *neural* cavity, because it contains the great nervous axis composed of the *brain and spinal cord;* whilst below the vertebral column, and inclosed within the ribs, when these exist, is a larger cavity, called the *hæmal* cavity, because it lodges the chief organs of the circulation, the heart and great bloodvessels; but besides these, it also contains the digestive, absorbent, respiratory, and reproductive organs, as well as the cords and ganglia of the *sympathetic nerves;* it forms therefore a distinct *perivisceral* cavity.

The nervous system is more highly developed than in the other subkingdoms; not only are the senses more perfect, but the brain or cerebral portion of the nervous system is highly developed, and exhibits a capacity to be associated with superior mental endowments. The jaws are formed by modified parts of the head, have no true analogy to limbs, and move vertically; teeth are often present, composed of dentine or modified bone covered with other hard material formed from the mucous membrane of the mouth; they constitute parts of the external skeleton. The alimentary canal, besides possessing a distinct stomach, salivary glands, and liver, is also provided with a pancreas. Special absorbent or lymphatic vessels exist, ending in a true blood-system of vessels, and containing a fluid in which colorless corpuscles are present; the absorbents proceeding from the alimentary canal convey chyle, and are named lacteals. The circulating system is highly developed, consisting of a heart divided into two, three, or four cavities, connected with distinct arteries, capillaries, and veins, and containing blood provided with both white and red corpuscles: a portal system of veins, transmitting blood from the alimentary canal to the liver, is also peculiar to the Vertebrata. In the lowest vertebrate animal known, viz., the Amphioxus or lancelet, an exception is found in regard to the blood and the heart, the blood containing only colorless corpuscles, and, in place of a single heart, numerous contractile sacs are found in the course of the chief bloodvessels. One at least of the so-called vascular glands, viz., the spleen, is always present in the Vertebrata. The law of bilateral symmetry prevails in a most perfect manner in the animal organs of locomotion and sensation; the organs of the senses are also double, excepting in the case of the single olfactory organ of the Amphioxus. Some of the Vertebrata, viz., the Mammalia, Aves, Reptilia, and higher Amphibia, breathe by lungs only; of the rest, a few of the Amphibia respire by lungs and gills, whilst all of the lowest class, Pisces. breathe by gills alone. Certain distinctive peculiarities, derived from the mode of development of the body of the embryo, and of the so-called visceral arches, belong to this subkingdom; these will be described in the chapter devoted to the subject of Development.

The vertebrate animals have been variously subdivided into groups, larger and fewer in number than the classes. Thus, the Mammalia and Birds form the so-called *warm-blooded* Vertebrata; whilst the Reptiles, Amphibia, and Fishes constitute the *cold-blooded* Vertebrata. A more scientific division requires, however, the recognition of the intimate connection between the Birds and Reptiles. It has been pointed out that the classes Mammalia, Aves, and Reptilia have, at no period of their existence, gills or organs intended for aquatic respiration; hence they have been grouped together as the *Abranchiate* Vertebrata; whilst the Amphibia and Pisces, always having temporary or permanent gills, have been included under a second group of *Branchiate* Vertebrata: these two groups are also distinguished by certain embryonic characters, which can only be alluded to here, the former possessing the so-called amnion and allantois, whilst the latter is destitute of both those structures, or possesses merely a rudimentary allantois. By another mode of classification (Huxley), the Abranchiate classes of the Vertebrata are separated into two groups, the one containing the Mammalia, and the other the Birds and Reptiles. The higher group, *Mammals*, have no branchiæ, but possess an amnion and allantois: they have two condyles to the occipital bone, a well-developed basi-occipital bone, no parasphenoid bone, and a simple lower jaw articulated with the squamosal and not with the quadrate bone; they possess mammary glands and non-nucleated colored blood-corpuscles. The lower group, *Sauroids*, comprising the Birds and Reptiles, likewise have no branchiæ, but possess an amnion and allantois: they have no parasphenoid bone, only a single occipital condyle, and a complex lower jaw articulated to the quadrate bone; they are unprovided with mammary glands, and have nucleated colored blood-corpuscles. A third distinct group, *Ichthyoids*, including the Amphibia and Fishes, possess branchiæ at some period of their existence, have no amnion, either no allantois or merely a rudimentary one, a parasphenoid bone in the skull, and nucleated colored blood-corpuscles.

It would be beyond the scope of this work to define the classes of the animal kingdom; but the characters of many of their internal organs will be given in the subsequent chapters on the special functions. With regard to the class *Mammalia*, however, in which man is included, an enumeration of the various orders of animals contained in that class is requisite, since frequent reference is made hereafter to the structure of the digestive and other organs in those groups. As usually defined, these orders are twelve in number, viz., the *Bimana*, *Quadrumana*, *Carnivora*, *Cheiroptera*, *Insectivora*, *Rodentia*, *Ruminantia*, *Pachydermata*, *Edentata*, *Cetacea*, *Marsupialia*, and *Monotremata*. The first of these orders, *Bimana*, contains the genus Homo, or Man, alone, who is regarded by the highest zoological authorities as of one species, although presenting many varieties. By Linnæus, however, Man was placed, together with the so-called Quadrumana, the apes, baboons, monkeys, and lemurs, and even the Bats, in a single order named the *Primates*. The above-named classes are grouped into three divisions; the first, named the *Deciduate-placental* Mammalia, includes the Bimana, Quadrumana, Carnivora, Cheiroptera, Insectivora, and Rodentia; the second, called the *Non-deciduate-placental* Mammalia, comprises the Ruminantia, Pachydermata, Edentata, and Cetacea; the third, named the *Implacental* Mammalia, includes the Marsupialia and Monotremata.

Mollusca. These animals, named from their *soft* structure (*mollis*, soft), have no internal segmented skeleton, like the Vertebrata; nor is the body segmented like that of the Annulosa, to be presently described; on the contrary, it is generally broad in proportion to its length, and belongs to what has been termed the *massive* type. They have no external hairs, feathers, scales, or horny or osseous plates; their soft integument is commonly protected by an external calcareous *shell* composed of many layers, secreted, one within the other, by the surface of a part of the body named the *mantle*. They have no jointed limbs, but the locomotive organs are always soft and merely *musculo-cutaneous*, usually forming the so-called foot or feet. The nervous system consists of scattered ganglionic masses, commonly disposed in three principal pairs, named, from their position or function, the *cerebral*, *pedal*, and *parieto-splanchnic ganglia*. The cerebral ganglia are very small in comparison with the brain of the Vertebrata, and there is no spinal cord. These ganglia are joined together by commissural nerve-cords; the cerebral ganglia, placed above the œsophagus, are connected by two cords, which pass down on the sides of the gullet, with the pedal ganglia, so that the gullet is inclosed or surrounded by the anterior part of the nervous system, or passes through it; longitudinal commissures also connect the cerebral with the parieto-splanchnic ganglia, but these latter and the pedal ganglia are not necessarily connected by direct commissures. The alimentary canal is provided at the mouth with soft non-segmented tentacles; it lies, as in the Vertebrata, in a distinct cavity named the *perivisceral cavity*, and is furnished with salivary glands and a largely developed liver. The heart, dorsal in situation, contains two cavities, and is connected with the systemic bloodvessels; the blood is corpusculated but colorless. Most molluscs being aquatic, breathe by gills, but some terrestrial genera possess pulmonary air-sacs.

In the highest Mollusca, the cephalopods or cuttle-fishes, there is frequently found a rudimentary cranium supporting the cerebral ganglia, and sometimes an internal horny or calcareous mass which may be taken to represent an internal skeleton.

The Molluscous classes, Cephalopoda, Pteropoda, Pulmogasteropoda, and Branchiogasteropoda, constitute a group named *Odontophora*, because they possess a peculiar apparatus in the mouth, armed with teeth, and movable, and sometimes called a tongue, but more appropriately the *odontophore* (Huxley). The remaining class, Lamellibranchiata, form a group destitute of the odontophore, and characterized by having a right and left bivalved shell and two lamelliform gills on each side of the body.

In the various classes of Mollusca, different parts of the soft body and appendages, which have received different names, are variously developed. Moreover, the alimentary canal follows such developments of the body, and thus becomes not only elongated, but bent; sometimes the concavity of the bend is directed towards the abdominal or under surface, and, as the chief nervous motor ganglia are placed on that side, such a bend is named a *neural flexure*, as seen in the Cephalopoda, Pteropoda, and Pulmogasteropoda; whilst sometimes the concavity is turned towards the dorsal region, or in the direction of the heart, and then it is termed a *hæmal* flexure, as in the Branchiogasteropoda: in the Lamellibranchiata it is at first neural, but is afterwards specially modified.

Molluscoida. The comparatively small subkingdom, Molluscoida, consists of animals which, as implied by their name, have close relations with the Mollusca, and were commonly classified with them; but, as suggested by Milne-Edwards, they may be more conveniently placed in a separate subkingdom, being much simpler in their organization. The nervous system consists of a *chief ganglion* with a few scattered ganglionic masses, or of a *single ganglion* only. The principal or single ganglion, as the case may be, is placed close to the oral aperture or mouth, sometimes having a nervous cord around the gullet. The alimentary canal is much flexed on itself, and sometimes is only provided with one opening, viz., the mouth. When an outlet also is present, it is placed, as a rule, near the mouth, the chief ganglion usually being placed between the two openings. A heart is not always present, and when it exists, is composed of but a single cavity. The oral aperture, except in one group (Appendicularia) is always surrounded with numerous *tentacles*, which are *ciliated*, and therefore probably respiratory, and are arranged either in a circle, or else upon long arms, or upon a band or ridge shaped like a horseshoe. Moreover, the mouth opens not directly into the œsophagus, but first into a long and sometimes very wide chamber or pharynx; and sometimes other so-called atrial or respiratory chambers are met with. In the Brachiopoda and Polyzoa the alimentary canal presents a neural flexure; in the Ascidioida, a hæmal flexure.

The classes of the Molluscoid subkingdom, all of which are aquatic, and mostly marine, consist of the Ascidioida, which include the tunicated marine animals, the Brachiopoda, and the Polyzoa or coralline polyps. It is in the Brachiopoda that the alimentary canal is sometimes destitute of any outlet, and that the remarkable contractile sacs, named pseudo-hearts, exist.

Annulosa. This subkingdom is distinguished, as its name implies, by its component animals having a segmented body, *i. e.*, a body composed of a series of more or less distinctly marked *annular segments or rings*, named *somites*, joined one behind the other. The body, therefore, of an Annulose animal is usually elongated, or belongs to the *longitudinal* type. Moreover, the surface of these segments is always firm, and sometimes even horny or calcareous, so as to form a dermal skeleton. In the higher classes, articulated or jointed limbs, also composed of external hardened integument with the soft parts within, and arranged symmetrically in lateral pairs, are met with. The central parts of the nervous system consist of numerous *pairs of ganglia* arranged one behind the other in a longitudinal direction, and connected by longitudinal cords. Usually each pair of ganglia is connected by a transverse commissural cord; but sometimes they are fused into a single mass, in which case, the double longitudinal cords are likewise blended. The first pair of ganglia, named *supra-œsophageal* or *cerebral*, are placed above the gullet, and the cords which pass downwards and backwards to the second pair of ganglia, named *sub-œsophageal*, embrace the sides of the gullet, which, therefore, as in the Mollusca, is completely surrounded by nervous matter, and is accordingly said to pass through or perforate the anterior part of the nervous apparatus: the remaining ganglia, with their longitudinal connecting cord or cords, are placed entirely below the alimentary canal, *i. e.*, along the underside of the body. In the higher forms, the sensory organs are highly developed, and a distinct contractile dorsal vessel, segmented, and provided with valvular openings leading into the *perivisceral cavity*, takes the place of the well-defined heart found in the Mollusca and Vertebrata. The blood is sometimes colorless and sometimes colored, and contains a few corpuscles.

As shown in the scheme of the subkingdoms already given, the Annulosa may be regarded as standing below the Vertebrata, side by side with the Mollusca, though, in some respects, the Mollusca present the higher organization. As the Mollusca have been divided into a larger and higher group, viz., the Odontophora, and a smaller and lower one, consisting only of the Lamellibranchiata, so also the Annulosa may be similarly subdivided. Thus the Insecta, Myriopoda, Arachnida, and Crustacea, form a large group, named *Arthropoda;* sometimes, even, raised into a distinct subkingdom under that name, or under the title Articulata: they are characterized by always having articulated limbs (ἄρθρον, *arthron*, a joint, πούς, *pous*, a foot). The smaller group consists of the class Annelida only, which have a softer integument, no jointed limbs, but simple lateral and symmetrical appendages, such as cirrhi or setæ. The rest of their organization, like that of the Lamellibranchiata, in comparison with the Odontophora, also presents a different and lower type of organization than the Arthropoda; and, indeed, they have by some been separated from the latter to form a distinct subkingdom under the name Vermes. They are, however, naturally associated with the higher Annulosa, from the annulated structure of their bodies, and the double ganglionated cords of their nervous system. The Arthropoda are further distinguished by the perfect bilateral symmetry, not only of the body and the organs generally, but even of their digestive and reproductive systems; also by the complex structure of the head, and by their highly developed organs of vision: the head has been shown to be composed of from four to six modified annuli or somites (Huxley); the jaws move transversely, and feelers or antennæ always exist; lastly, no vibratile cilia have been seen either in the embryonic or adult condition of any of the Arthropoda. On the other hand, the Annelida, instead of a hard external skeleton and jointed limbs, have a soft body with simple appendages; the head never contains even four modified somites (Huxley); the organs of sense, especially the eyes, are very simple; there is no distinct valved dorsal vessel communicating with the perivisceral cavity; most of them possess, either in the embryonic or adult condition, vibratile cilia on, or in some part of, their bodies; and, lastly, they are nearly all provided with peculiar vessels, named *pseudo-hæmal*, which frequently contain a *colored* corpusculated fluid.

Annuloida. Standing below the Mollusca, we found simpler soft-skinned animals grouped together under the name Molluscoida, as suggested by Milne-Edwards; and so below the Annulosa are arranged, by Huxley, under the name Annuloida, which is intended to show their relations with the Annulosa, the class Scolecida, containing certain marine worms, the entozoa or parasitic worms, and the rotiferous animalcules, and the class Echinodermata, or star-fishes. These Annuloid animals approach the lowest Annulosa, *i. e.*, the Annelides, in the worm-like form of the bodies of many of them; in the frequent presence of cilia, at least in the embryo condition; in the possession of a peculiar set of vessels, named the *water-vessels*, in the Scolecida, and the *ambulacral vessels*, in the Echinodermata, which may represent the pseudo-hæmal vessels of the Annelida. But the Annuloida are distinguished from the Annulosa by the imperfect segmentation of the body, or by the complete absence of segmentation, and by the non-existence of bilateral symmetrical limbs or appendages. The nervous system never presents the double longitudinal ganglionated cord, but consists of either one, two, or four *supra-œsophageal ganglia* situated in the fore-part of the body, above or upon the gullet, from which delicate branches merely ramify forwards through the head, and backwards through the body; in the Echinodermata, in accordance with their horizontally radiated form, the ganglia, which might be termed *circa-œsophageal*, are proportionally multiplied, are connected with cords surrounding the oral aperture, and give off radiating branches. Eye-spots are present in the Rotifera and in some Echinodermata, but the other sensory organs are rudimentary or absent. In most of the Annuloida, moreover, that remarkable mode of development is observed, by which the ova do not immediately form perfect animals, but larvæ or embryonic forms, within which, by a subsequent process of evolution, perfect animals are produced. This kind of development is known as *alternate generation*.

Cœlenterata. This extremely natural group, established as a subkingdom by Frey and Leuckart, consists of animals, the bodies of which have a much simpler structure than those even of the lowest Annuloid or lowest Molluscoid animals; although the radiated form, common to both the class Actinozoa or sea-anemones, and the class Hydrozoa, which includes the Medusæ, Acalepha or sea-nettles, and Hydroid Polyps, suggests resemblances with the Echinodermata on the one hand, and with the Polyzoa on the other. The body of the Cœlenterata is hollow; the alimentary canal, destitute of special glands, is extremely short and simple, for it has but one external aperture, viz., the oral opening or mouth, its hinder end opening widely into the cavity of the body itself; hence the name Cœlenterata (κοῖλος, koilos, hollow; ἔντερον, enteron, intestine). The walls of the body are also characteristically simple, being composed of an outer layer named the ectoderm, and an inner layer named the endoderm; both are composed of nucleated cells, and apparently in the simplest forms, as in the Hydra, possess the same physiological properties, for they are equally capable of digesting food received into the hollow of the body, even when this is turned inside out. Around the oral opening are usually found numerous prehensile *tentacles*, usually hollow, and *never provided with vibratile cilia* upon the surface, like the tentacles of the Polyzoa. Most of the Cœlenterata have, in their ectoderm, little oval elastic sacs containing, besides fluid, a long barbed and serrated filament, which is projected beyond the sac on any irritation, and so acts offensively or defensively, destroying soft animal prey, and even irritating the human skin. These sacs are named *nemato-cysts* or *thread-cells*, and their irritating qualities have given rise to the term sea-nettles, applied especially to the Acalepha. Somewhat similar bodies, it may be added, are found in certain Mollusca and Scolecida. The nervous system of most of the Cœlenterata has hitherto escaped detection; but in the Ctenophora or ciliograde forms, such as the Beroe, it consists of a *single* or *compound ganglion* placed in the centre of that part of the body opposite to the oral aperture, and of nervous filaments radiating from it. Doubtful ganglia have been described as existing in the base or attached part of some of the Actinozoa or sea-anemones. No organs of circulation exist; but the cavity of the body is prolonged in the form of canals, even into the tentacles, and sometimes these are lined with cilia, so that they may not only convey nutriment, digested in the short alimentary canal, and passed at once into the cavity of the body, but may, as well as the general surface, act as respiratory organs.

Protozoa. The remaining and lowest classes of animals constitute the subkingdom, Protozoa, which includes the Infusoria, the Spongida or Porifera, the Rhizopoda or Foraminfera, and the Gregarinida. The Protozoa agree in the marked simplicity of their organization, as compared even with the lowest of the Molluscoid, Annuloid, or Cœlenterate animals. With the Annuloida, however, some of them present a certain affinity, as shown by the class Infusoria having at one time been made to include the rotiferous or wheel-animalcules of the Annuloid subkingdom. The Protozoa have, so far as is known, *no nervous system;* they have no proper alimentary canal or circulating organs; nor do any of them contain a large body-cavity, like the Cœlenterata, bounded by two layers, an ectoderm and an endoderm. They are composed of a minute mass, or of aggregate masses, of a soft substance, usually designated *sarcodous*, possessing more or less contractility; within this there is often found a central nucleus, and frequently one or more peculiar cavities of variable size, named *contractile vesicles.* Nearly all inhabit either fresh or salt water, but a few live in the interior of more highly organized animals. Most of them possess cilia used either as locomotive organs, or for the purpose of creating currents in the water in which they live. They are usually multiplied by the simplest forms of development, such as gemmation or fission, as will be hereafter explained.

Of the Protozoa, the class Infusoria certainly stand higher than the rest; their soft sarcodous substance is firmer on the surface than in the interior, where it is sometimes almost fluid. In the typical forms, a small orifice on the surface, surrounded by cilia, constitutes a sort of mouth; and hence the Infusoria have been grouped together under the name of *Stomatoda*, or Stomatode Protozoa. This mouth leads into a shallow cavity or short tube, wnich ends abruptly in the soft central sarcode, and which is regarded as a *gullet*, or rudiment of an alimentary canal. The contractile vesicles in their interior, sometimes also named *vacuoles* or *water-receptacles*, are more numerous than in other Protozoa. The Infusoria are also particularly distinguished by the importance of their cilia, which are sometimes single, but more frequently very numerous on the surface of their bodies, and which serve not only for locomotion, but also sometimes to direct the food into their short gullet. By the possession of locomotive and other cilia, they approach the Rotifera and other Scolecida; also by the analogy between their contractile vacuoles, which are sometimes ramified, and the water-vessels of these Annuloida; and, lastly, by their occasionally undergoing, like the latter, a process of *encystation*, preparatory to developing young in their interior. They are distinguished from the other Protozoa by the peculiar possession of the so-called nucleus and nucleolus, two parts essentially concerned in that form of the reproductive process known as *conjugation.* The Infusoria, like the remaining Protozoa, are developed also by gemmation and by fission.

The remaining Protozoa present no oral aperture or mouth, and hence have been grouped together under the name *Astomata*, or Astomatode Protozoa. They are, in all respects, more simple in structure than the Infusoria, their sarcodous substance being destitute of any firmer outer portion or envelope, but being uniformly soft throughout, and sometimes containing only a single contractile water-vesicle. The Spongida consist of aggregations of these minute sarcodous masses, which are sometimes ciliated, and are always, as well as the allied sarcodous unicellular independent animals, such as the Amœba, capable of varying their form by thrusting out broad or narrow processes or lobes, sometimes named feet. The Rhizopoda are furnished with beautiful coriaceous or siliceous shells, sometimes simple, sometimes many-chambered:

in them, the sarcodous processes are extremely long and thread-like, often very numerous, like roots (*rhizon*, a root; *pous*, a foot), and frequently coalesce at their extremities; they are named *pseudopodia;* they are often thrust through the minute openings in the perforated shells, which have suggested the name Foraminifera given to these interesting and abundant animals. Lastly, in the Gregarinida, the soft body is destitute of envelope, contractile processes or pseudopodia, and contractile vacuoles, and presents only a nucleus in its interior, with a contained nucleolus. They constitute the lowest and simplest forms of the animal series, being unicellular, and composed of naked nucleated portions of sarcode or protoplasm, elsewhere mentioned as *gymnoplasts.* The reproduction of these lowest Protozoa is also extremely simple, being sometimes, at least apparently, non-sexual, a certain portion of the parent animal, which first becomes encysted, undergoing direct transformation into a mass of young.

Position of Man in the Animal Series.

Such being the outlines of the vast array of the animal kingdom, the zoological position of man is, as we have seen, at its very summit; for he occupies the highest position in the class Mammalia, in the subkingdom Vertebrata. Whether he should be arranged with the Quadrumana in one order, the *Primates* (Linnæus), or be separated from them to form a distinct order, *Bimana* (Blumenbach, Cuvier), or be still further distinguished from the animals by being placed in a separate subclass, *Archencephala* (Owen), is a purely zoological question, not to be discussed here. Whichever view comes to be ultimately adopted, the anatomical characteristics of man are well marked, even when his structure is compared with that of the highest anthropoid apes. His structural peculiarities will be found to depend chiefly on the following conditions, viz., the perfect adaptation of his skeleton and muscles to the erect attitude maintained upon the hinder extremities exclusively, so as to set entirely free the anterior limbs for special, but non-locomotive, purposes; the comparatively soft nature of his food; his want of special organs of offence; and, lastly, the higher organization of his brain to fit it to become the instrument of superior intellectual endowments. These points will be hereafter respectively considered in the chapters on locomotion, mastication, and the functions of the brain. It may, however, here be added, that the general form of the human body and its parts is rounder, fuller, and more richly modelled, than that of any of the animals nearest to him; and that his skin is almost destitute of hairy covering. Physiological, social, moral, and psychical differences also distinguish him in a remarkable manner from any animals. Such are—his slow growth, associated, doubtless, with the ultimate perfection of his organization and powers; his necessarily long-continued dependence on his parents; his adaptability to all kinds of climate, soil, and food; his marked improvability, dependent on the subjection of his instincts to his reason; his perception of the abstract beyond the concrete; and, as consequences of this, the formation of abstract ideas, the invention of speech and language, communication of mind with mind, the preservation and transmission of knowledge from one generation to another, a moral sense of duty to others and to himself, and a consciousness of relations, mysterious though they be, to the present, to a past and a future, to the finite, and to the Infinite.

Types, Laws of Form, Homologies, Analogies, Unity in Variety, Genetic Relations.

The zoological relations of man with the entire animal kingdom, are necessarily associated with anatomical and physiological resemblances and differences more or less marked in special cases. The determination of these is the proper object of comparative anatomy and physiology. The former science has been cultivated so far as to lead to the discrimination of certain general *plans* or *types* of form observable in the animal series, which are indicated in the several sub-kingdoms. At least, there can be little doubt as to the apparent distinctness of the vertebrate, molluscous, annulose, cœlenterate, and protozoic types; though it is possible that the molluscoid and annuloid groups are subtypical, and attached respectively to the molluscous and annulose types. The ideal plans of these types of course involve every *leading* or essential feature in their structure; but one very simple view of them, is that expressed by a comparison of transverse sections through the body in each case, as is shown in the following diagrams, Fig. 45.

Thus, a transverse diagrammatic section of the body of a *Vertebrate* animal, V, shows two chambers, or *perivisceral cavities*, an upper smaller one, and a lower larger one, separated from each other by the more solid or *axial* part of the vertebral column, occupying the position of the so-called dorsal cord of the embryo. In the upper tubular chamber, the *neural* cavity, lies the section of the great nervous axis or centre; in the lower chamber, or *hæmal* cavity, are lodged the double or laterally symmetrical sympathetic nerves, above, the alimentary canal in the middle, and the heart, or central organ of the blood system, below.

A transverse section of a *Molluscous* animal, M, shows but a single body-cavity or perivisceral cavity, in which the heart is placed above, the alimentary canal in the middle, and the chief portions of the nervous system, *i. e.* the double laterally symmetrical pedal and parieto-splanchnic ganglia, at the lower part.

A similar section of an *Annulose* animal, A, presents also a single perivisceral cavity, having as in the Mollusc, the alimentary canal in the middle, the double ganglionated nervous cords below, and the elongated dorsal circulating vessel above.

On comparing the Molluscous and Annulose types, it appears that the longitudinal segmentation of the latter is the chief difference, the typical plan being otherwise the same. On comparing these two with the Vertebrate type (which can best be done by supposing the latter to be *inverted*, so that its abdominal surface is turned upwards, as at *v*), it will be seen that their single perivisceral cavity, with its contents, appears to represent the hæmal cavity of the Vertebrate animal and its contents; and that the vertebral column, or dorsal cord, the neural cavity, and its great nervous axis, the cerebro-spinal centre, are altogether superadded parts in the Vertebrate type.

A transverse section through a *Molluscoid* animal, Md, shows also a single perivisceral cavity, having the alimentary canal in the middle, the single or chief ganglion on the side next the locomotive organs, and the rudimentary heart on the opposite side; but these sides are no longer obviously under and upper, as in the Mollusca.

No single diagram will represent the diverse plans of the Annuloid animals.

In the highest forms, however, there is no true heart or central circulating organ, and the chief nervous ganglion sends off nervous cords scattered through the body; but there is still a central alimentary canal, distinct from and lying in a perfect perivisceral cavity.

Fig. 45.

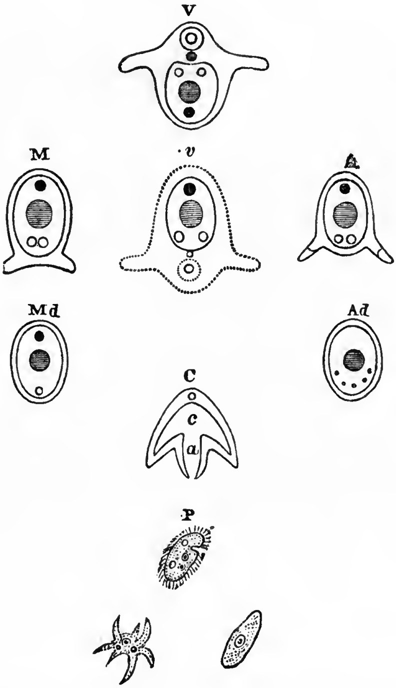

Fig. 45. V. Transverse section of Vertebrate type or plan. v, the same inverted. M. Transverse section of Molluscous type. A. ditto Annulose. Md. ditto Molluscoid. Ad. ditto Annuloid. C. Longitudinal section of Cœlenterate plan. *a*, alimentary canal; *c*, body-cavity. P. Diagrams of Infusorial, Amœbous, and Gregarinidous Protozoic plan, highly magnified. In the upper six of these diagrams, the alimentary canal is shaded with cross lines; in them, and in the plan C, the nervous cords are left as open rings; the heart or circulatory vessel, when present, is represented black.

The subtypical position of these last two forms, in regard to the Mollusca and Annulosa, is obvious; of these plans, or types, they are simplifications, or, as in the radiated forms of the Echinodermata, modifications in points of detail.

The *Cœlenterate* type is altogether different and lower. A transverse section will no longer reveal its plan. A *longitudinal* section, C, shows the complete absence of a perivisceral cavity, for the alimentary canal, *a*, now ends in, or is part of, the general cavity of the body, *c*; there is no heart or central circulating organ; and the nervous centre, when such can be detected, is placed at the end of the animal opposite to the oral aperture.

Lastly, the *Protozoic* type is still more simple. A section of their bodies no longer indicates even a distinct body-cavity. A diagram of the highest, or Infusorial form, shows a unicellular bi-nucleated sarcodous mass, with a firm exterior bearing cilia, a short gullet ending abruptly in the mass, and one or more internal contractive vesicles; but no nervous or circulatory apparatus. The Amœbous form has not even a short gullet; but the soft mass, now without a distinct envelope, and changeable in its shape, has a single or double nucleus, and sometimes also a contractile vesicle; aggregates of such masses may occur. Lastly, the lowest, or Gregarinidous form consists of a simple gymnoplast, or naked nucleated cell, composed of a minute mass of protoplasmic sarcode, containing a single nucleus, with its included nucleolus.

The science of *philosophical anatomy* further endeavors to penetrate the fundamental laws at work in these several plans of construction. Considered generally, it is seen that all animal forms exhibit a more or less *axial* mode of growth; that all are more or less perfectly *bilaterally symmetrical*, even the spirally convoluted Gasteropodous Molluscs presenting two, though unequal, halves, and the radiating Echinodermata also exhibiting an imaginary *median plane* of partition. It is further seen that the *spheroidal* form is common amongst simple animals, ova, and commencing tissue-cells; the *radiate* form, in many of the lower animals; and *spiral* arrangements, in others, as well as in the organs or parts of animals higher in the scale; lastly, *repetitions* of similar parts are found to prevail in the elongated animals, and in many organs and tissues.

Furthermore, it is shown, on comparison, that like parts in the same animal, or in different animals, may be extremely modified in form and structure, to suit different purposes, and yet not lose their *essential identity;* in such case, they are said to be *homologous* parts. Thus, each vertebra, or vertebral segment, is homologous with every other vertebra, however highly developed these may be, as in the back, or however they may be simplified, as in the sacrum or coccyx: even the cranial segments, specially modified as they are, have been regarded by many as homologous with vertebræ. Again; the upper limb of man, and its several bones, are homologous with the lower limb and its bones, part for part, although the one is fitted for prehension and the other for locomotion. The shoulder-bone and collar-bone together are the homologues of the hip-bone; the humerus, of the femur; and the radius and the ulna, of the tibia and fibula. Again, the carpus and metacarpus are homologous with the tarsus and metatarsus; the three phalanges of the four fingers with those of the four outer toes; and, lastly, the thumb, having two phalanges, is the homologous part to the great toe, which also has two phalangeal bones. The same law of fundamental homology is evident in comparing, not merely the parts of the same animal, but those of the different animals of the same type with each other; thus the upper prehensile limb of man is homologous with the equally prehensile arm of the ape, with the locomotive fore-limb of the mammalian quadruped and reptilian lizard, with the wing of the bat and the more specially modified wing of the bird, with the anterior flipper of the seal, the single flipper of the porpoise, the paddle of the turtle, the fore-foot of the newt, and the pectoral fin of the fish; for all these parts, however different in form and use, are modifications of the same fundamental portion of the vertebrate frame, *i. e.*, of the *anterior lateral appendage.* So also the lungs of the mammalia, birds, reptiles, and amphibia, are homologous with the air-bladder of certain fishes, though this ceases in most cases to be in any way a respiratory organ. Passing from the Vertebrate to some other type, as *e. g.*, to the Annulose, we find homology in the different somites of an insect or a crustacean, however they may be modified or fused together; and so also the antennæ, the jaws, the large pincers, and the locomotive or swimming feet of the lobster, are obviously homologous parts resulting from the modification of typical lateral appendages. Homologies are also apparent between like parts of animals constructed upon totally different types; but they are fewer in number and less apparent, sometimes obscure or even doubtful; thus there can be no doubt that the stomach, salivary glands and liver of the Mollusca, and even similar parts of the still lower subkingdoms, are homologous with the alimentary canal and its appended glands in the Vertebrata; so also the supra-œsophageal ganglion of the Mollusca and of the Annulosa, with which the nerves of special sense are connected, is probably homologous, on the one hand, with the sensory portion of the cerebrum of the Vertebrata, and is certainly so, on the other, with the single ganglion of the Molluscoida, and of the Annuloid Rotifera. But with regard to the locomotive organs in animals belonging to different subkingdoms, the homologies are not evident, as, *e. g.*, between the legs of quadrupeds, the legs of insects, and the locomotive organs of the Mollusca. Further, as already mentioned, though the heart of the Mollusca, and the dorsal vessel of the Annulosa, are really the centres of the circulating system in those animals, it is doubtful whether they are strictly homologous with the heart of the Vertebrata; for the circulating organs in these lower animals are by some regarded as possibly homologous with the lymphatic system of the Vertebrata, in a few of which animals lymphatic hearts are met with.

Homology must not be confounded with another, but less important, relation which often exists between the parts of animals, and which is designated by the term *analogy*. Parts or organs sometimes perform corresponding functions, and yet are not homologous structures; they are then said to be analogous parts. Thus the lungs of the Vertebrata are analogous to the pulmonary sacs of certain snails, and to the air-sacs of spiders; but, from their positions and connections, are evidently not homologous parts. So, too, the wings of the bird and those of the insect, and, again, the gills of the fish and the gills of the lobster, are analogous, but not homologous organs.

Although the essential resemblances between man and the higher animals, on the one hand, and the lowest animals, on the other, become at length so obscure, that the homology between a vertebrate animal and a protozoon is no longer recognizable, so far as special *organs* are concerned, still a profound homology remains throughout the whole animal series, viz., that of the *tissues*. Thus, in the lowest animals, a simple contractile protoplasm is the homologue of the highly complicated muscular tissue of the higher animals, and the nerve-cells of the most minute ganglion represent those of the large cerebrum even of man. Moreover, in this point of view, as already mentioned, the simple gymnoplastic nucleated cell-like Gregarina may be regarded as homologous with a nucleated gymnoplast from the tissues of the higher animals or of man.

Still further, comparative physiology recognizes homologies in vital actions. Homologous organs and tissues perform *homologous func-*

tions, and possess homologous *vital properties*. The phenomena of nutrition and reproduction, and the property of contractility giving rise to motion, are manifested in, or possessed by, all animals; sensation and voluntary motion in most. Experimental physiology rests upon this fundamental unity of functions as well as of plan; and recognizing the resemblances, whilst allowing for the differences, between man and the lower animals, it has succeeded in eliciting many important physiological facts and doctrines, which illustrate the functions of the human body, more especially, it may be added, those of the various parts of the nervous system.

Due consideration being given to all the preceding facts, to the small number of typical plans of animals, to their known modifications or variations, on the one hand, and to their mutual points of approximation or alliance on the other, and especially to the higher laws of homology and form,—a certain "*unity*" is seen to be manifested amidst all the "*variety*" which prevails; and more or less broken, yet *gradational*, lines can be traced through the animal series.

In conclusion, it may be remarked that the profound study of the entire chain of homologies connecting animals of the *same* type with each other, has led to the opinion of the existence of certain still more intimate relations between them, viz., those of a *genetic* kind, extending through vast periods of time, and expressed in the formula of continuous "descent with modification." The possibility of such genetic relations has even been surmised in regard to animals of the *different* types, and they have likewise been supposed to include man himself, considered as the highest existing animal form upon the earth.

RELATIONS OF MAN AND ANIMALS WITH PLANTS.—RELATIONS OF THE ANIMAL AND VEGETABLE KINGDOMS.

Besides the more intimate relations which exist between man and animals, and between animals themselves, there are other and highly important relations between the animal kingdom, man inclusive, and the vegetable kingdom; these relations are of three kinds, viz., of resemblance, difference, and dependence. To explain them, it is necessary to give some preliminary information concerning the vegetable kingdom.

Outlines of the Vegetable Kingdom.

Classification.—By Linnæus, plants were divided into the *Phanerogamia* or *Flowering* plants, and the *Cryptogamia* or *Flowerless* plants; but by Jussieu and the followers of the Natural system, a tripartite classification has been adopted into *Dicotyledonous*, *Monocotyledonous*, and *Acotyledonous* plants; the two former together corresponding with the Phanerogamia, and the latter with the Cryptogamia.

The Dicotyledona include the most highly developed forms in the vegetable world; they all produce true leaves, flowers, and seeds; they are so called because the seed possesses *two seed-lobes* or *cotyledons*, which, when developed in germination, form two little embryonic leaves. The stems of these plants are formed by the regular growth of new concentric layers of vascular and woody tissue deposited in succession one outside the other, the earliest formed layer immediately surrounding the central soft part called the pith, and the latest formed layer being that placed immediately beneath the cuticle or bark;

hence the Dicotyledons are also named *Exogens;* their leaves present a branched and reticular arrangement of the so-called veins. The Dicotyledons include the great majority of the European flora, comprehending the timber, forest, and fruit trees, shrubs, and most of the firm-stemmed herbaceous plants.

The Monocotyledona also produce true leaves, flowers, and seeds; but, as their name implies, the seed has only *one seed-lobe* or *cotyledon*, which germinates into a single embryonic leaf. Their whole structure is simpler than that of the Dicotyledona. The vascular and woody tissue of their stems is not deposited in successive concentric layers; but is collected into numerous bundles, diffused or scattered through all parts of the cellular or pithy structure of the stem; hence these plants are also named *Endogens.* Their leaves are characterized by a parallel arrangement of the veins. The Monocotyledons are fewer in number than the Dicotyledons, and are rarer in Europe. Monocotyledonous trees, such as the bananas and the palms, are found only in hot countries. Most of these plants are herbaceous, such as the orchids, the irids, amaryllids, and lilies, the asparagus, colchicum, and arum, the sedges and the extensive and varied family of grasses, including the bamboo, sugarcane, rice, maize, wheat, rye, barley, oats, and all the varieties of meadow-grass.

The *Acotyledona*, corresponding with the Cryptogamia, produce neither true leaves, flowers, nor seeds, and accordingly, as their name implies, have no seed-lobe or cotyledon. They are reproduced by much more simple structures, viz., single cells, often quite microscopic, named *spores.* In the larger kinds, a stem is developed, consisting of both vascular and cellular tissue, the former being in that case, either collected into a central mass, or into a few large regularly folded masses; these are named the *vascular* Acotyledons; they possess leaves or leaf-like parts, sometimes named *fronds.* In other and simpler kinds of Acotyledons, there is no vascular tissue, the entire plant being formed of cells; hence these are called *cellular* Acotyledons. The stem of the vascular Acotyledona and of one family of the cellular group, viz., the mosses, grows or increases only at the point or apex; hence these have been named *Acrogens;* whilst the remaining cellular forms have neither stem, root, nor leaves, but consist of a fused mass of cells, called a *thallus*, and hence are named *Thallogens.* Amongst the vascular Acotyledons are found the lycopodiums, or club-mosses, some of which attain the height of trees; the ferns, some of which, like the Cycas, also reach a great height and size; and lastly the equisetums. To the cellular Acotyledons belong the mosses, the enormous family of fungi, including the large boletuses and agarics, the truffles and morells, and all the minute microscopic fungi, such as the Penicillium, Mycetum, Oidium, Botryllus, and others; also the various lichens, and lastly the algæ or confervæ, some of which, such as the sea-weeds, are of gigantic dimensions, whilst some, like the Desmideæ, Diatomaceæ, Oscillatoriæ, Volvocinæ, Protococci, Monadinæ, and others, are quite microscopic; many of these have been, from their manifestation of movement, erroneously classed with the infusorial animalcules. Amongst the fungoid group, the *Mycetozoa*, and, amongst the confervoid forms, the *Vibrionia*, occupy a doubtful position between the animal and the vegetable kingdoms.

Structure and Functions of Plants.—Plants, like animals, have a definite organization and structure, and are endowed with special functions and properties, which are the subjects of study in vegetable anatomy and physiology. The characteristic functions of plants are those of nutrition and reproduction; for in the few instances, to be hereafter mentioned, in which partial or general movements occur in them, such movements are involuntary and, when their purpose is evident, concur in one or other of the two proper vegetative functions. The chief nutritive organs in Exogens, Endogens, and Acrogens, are the *roots*, with their soft terminal absorbing points named *spongioles*, the *stem*, and its *branches*, and the *leaves* or *leafy fronds.* The roots, the proper organs of absorption, take up water holding in solution carbonic acid, ammonia, sulphates, phosphates, and other saline materials, constituting the ultimate food of plants. The stem and branches convey these materials, now somewhat enriched by substances already contained in the plant, upwards to all parts, in the form of the ascending sap. The leaves are the seats of the active elaborative vito-chemical processes of the plant: it is from their surface that the excess of water is exhaled by a process of *transpiration*, from little apertures or mouths named *stomates*, found especially on the under side of the leaf; through these stomates, the leaves may also *absorb* vapor and gases. In the leaves, also, the processes of *assimilation* are performed, as well as those of *respiration*, which in plants is rather an assimilative than a respiratory act, consisting essentially in the fixation of carbon, derived from carbonic acid, together with the elements of water and ammonia, and in the evolution of oxygen. These processes occur under the influence of solar light, and in this way, not only chlorophyll, the green coloring matter, but other ternary and quinary constituents are prepared, such as the vegetable acids, the carbhydrates, starch, sugar, gum, cellulose, and lignin or woody fibre, and also the hydrocarbons or fixed and volatile oils; and moreover by the fixation of nitrogen or ammonia, there are formed those most important albuminoid substances, gluten, fibrin or legumin, which are necessary to all the growing parts of plants, and which are stored up abundantly in the seed. The fluids returned from the leaves, supply materials, chiefly cellulose and lignin, for the formation of the new parts of the stem and roots, and so assist in building up the passive framework of the plant; and they also deposit in their path, by processes of secretion, special chemical compounds, such as the essential and fixed oils, and the vegetable alkaloids or bases, exemplified by quinine, morphia, thein, caffein, and asparagin; and finally even, it is said, throw off by an excretory process, chiefly by the roots, residual substances which would be injurious to the plant. The decomposition of carbonic acid, and the evolution of oxygen, which takes place in the mixed assimilative and respiratory functions of plants, are phenomena the reverse of those which occur in the respiration of animals, and by which oxygen is absorbed and carbonic acid given off. In the germination of the seed, and at the period of perfection of the flower, carbonic acid is, however, also given off by plants. In the absence of light all parts of plants are said to exhale carbonic acid, which must always exist in their fluids, and then escapes decomposition. In some plants, certain special fluids, more secretive than nutritive, constituting the so-called *latex*, circulate in peculiar vessels named laticiferous. The reproductive functions of all the phanerogamic plants are performed by the agency of the flowers, or rather by that of their most essential parts, viz., the *pollen* and the contents of the *ovule*, which are brought together by the various contrivances manifested in the structure and arrangement of the stamens, anthers, pistil, and carpels. The petals and sepals of the corolla and calyx, when present, are supporting, protective, ornamental, and attractive to insects, which aid in conveying the pollen to the stigma; bracts, stipules, and tendrils are also efficient organs of protection and support. *Buds* are the means of multiplication by division of the individual, seeds and spores by a true reproductive process. Within the fertilized ovule the *embryo*, with its one or two cotyledons, is formed. In the cryptogamic flowerless plants, instead of a seed containing an embryo, *sporangia*, or other organs, appear on the fronds or thallus, and produce within them the so-called *spores*. The nutritive processes of the cellular thallogens are accomplished without the aid of woody or vascular parts.

The vegetable textures of which all plants are built up, are the so-called *woody tissue*, Fig. 47, *f*; the *vascular* or *tubular* tissue or *ducts*, *c*, *d*, *e*; and the *cellular* tissue, *a*, *b*. Certain parts, such as the pith, *a*, the cuticle, *b*, and the embryo of the higher plants, consist entirely of cellular tissue, *i. e.*, of an assemblage of coherent vegetable cells. Even the woody, *f*, and vascular, *c*, *d*, *e*, tissues are produced by various modifications and functions of such vegetable cells. As already mentioned, the thallogens are exclusively composed of such cells; and the very simplest forms of them, the lowest Algæ, consist but of a single cell, or are unicellular, Fig. 46, *b*. The ovule of the highest plant, and the simple spore, are but different evolutions of this primitive vegetable cell.

Ultimately, therefore, all the vital functions performed by plants, viz., the so-called *vegetative functions*, whether *nutritive* or *reproductive*, are accomplished by the agency of cells. A vegetable cell, Fig. 46, *c*, consists of the following parts: *First*, the *cell-contents* or *endoplast*—a soft, usually colorless, fluid, slimy, or granular, mass, which always contains, when growing, some of the quinary nitrogenous, albuminoid matter or *protoplasm*, absolutely essential to all vital activity: the outer layer of this endoplast is rather firmer than the rest, and has been named the *primordial utricle;* within, or upon, the endoplast is fre-

Fig. 46.

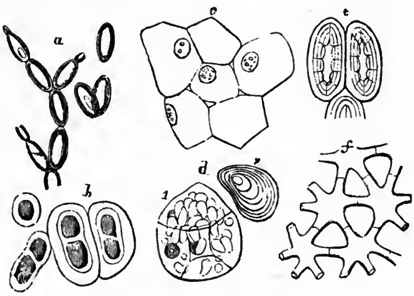

Fig. 46. Examples of vegetable cells (Schleiden, and others). *a*, conjoined and separate oval cells of the yeast plant, torula cerevisiæ; *b*, cells of an algaceous plant, hæmato-coccus binalis, single, double, and clustered in fours; *c*, polyhedral cells, with nuclei, nucleoli, clear contents, and distinct walls, from the onion; *d* 1, polyhedral cell from the potato, containing a nucleus, and many starch-grains; 2, a single starch-grain more highly magnified, showing the concentrate striæ; *e*, cells filled with concentric deposit of ligneous matter, from the gritty part of a pear; *f*, stellate cells, from the pith of the rush, showing the union of the different points of the cells, and the intercellular spaces. Moderately magnified.

quently found, at least in growing cells, *b*, *c*, *d*, a smaller vesicular body named the *nucleus*, having in its interior one or two *nucleoli*, and constituting apparently a special centre of activity or growth. The entire endoplast, thus described, is the essential part of every vegetable cell. Outside the endoplast, is the *second* elementary part, named the *cell-wall* or *periplast*, *c*, *d*, *e*, which is at first, always thin, homogeneous, and transparent, and consists of the ternary

Fig. 47.

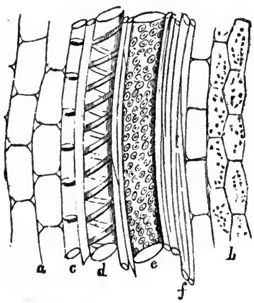

Fig. 47. Example of modifications of vegetable cells, forming the so-called vascular tissues of plants; from the Italian reed (Schleiden). *a*, elongated polyhedral cells of the pith; *b*. cells of the cuticle, containing granules of chlorophyll; *c*, annular vessel, formed by the union of cells, and absorption of their intermediate septa; *d*, spiral vessel, formed by union of cells, and deposit of ligneous matter in spiral lines; *e*, dotted vessel or duct, formed by another mode of ligneous deposit within coalesced cells. To the right of this are woody fibres, *f*, formed by solidification of fusiform cells with lignin. Moderately magnified.

cellulose tissue; its office is evidently protective and supporting, but it permits of the passage of dissolved materials into and out of the endoplast which it surrounds—physical processes essential to nutrition and growth. The cell so constituted may alter in size and shape, may coalesce with other cells, Fig. 47, *a*, may have its cell-wall perforated, *c*, or thickened by internal deposits, *d*, *e*, or its contents may be altered in the most diverse ways. Again, it may multiply itself by a gradual constriction and division of its endoplast, such divisions commonly affecting the nucleus also, and by simultaneous growth inwards of the periplast or cell-wall, so as to cut the primitive cell into two cells, each of which may again undergo a like process of subdivision, Fig. 46, *b*. Grouped together in specially arranged forms and plans, more or less modified to suit various purposes, and held together by an intermediate cellulose uniting substance,—such cells, yet retaining their own independent powers, though co-operating with myriads of others—serve to build up even the highest plants, constitute their organs, and perform their various functions, nutritive or reproductive. Or, one such cell, as in the unicellular microscopic Algæ, *b*, may embrace within its minute sphere of action all the characteristic vegetative processes—absorption, elaboration, and respiration, the growth of its own simple structure, and the reproduction, by division of its endoplast and periplast, of its own species,—thus evincing the close relationship of reproduction with nutrition, and the unity of all the so-called organic or organizing processes. Unless in the case of the Mycetozoa, it is not certain that any naked protoplasm, or gymnoplasts, exist in the vegetable kingdom.

Besides containing all the chemical elements found in animals (see p. 86), even fresh-water plants may have a certain quantity of iodine in their composition; whilst the marine algæ contain both iodine and bromine.

Resemblances between Animals and Plants.—Living animals and plants resemble each other in all the particulars which characterize bodies belonging to the organic kingdom of nature. They are both organized, *i. e.*, composed of parts, *complex* or *elementary*, named organs, destined for special uses; or, in the simplest or lowest forms of both kingdoms, they consist of distinct structures or tissues, manifesting vital properties, capable of being called forth by appropriate stimuli. In chemical composition they likewise present a general resemblance, though it was formerly supposed that they were specially distinguished in this respect. Animals were known to contain proximate constituents, named quaternary, because supposed to consist of four elements—carbon, hydrogen, oxygen, and nitrogen—such as albumen and fibrin; while plants were said to contain substances of ternary composition only, *i. e.*, consisting of carbon, hydrogen, and oxygen. But plants, as is now well known, also contain albuminoid substances, such as gluten, legumin, and others, which, indeed, constitute their most essential living parts; whilst the ternary compounds formed within them, viz., woody fibre or cellulose, starch, sugar, and oil, are merely the supporting portion of the vegetable fabric, or deposits in the general tissues of the plant. Moreover, starch, sugar, and even a peculiar form of cellulose, are found in the bodies of animals, the latter in the skin of certain of the Tunicata, starch and sugar, even in the highest animals and in man. As regards their vital properties and functions, animals and plants also resemble each other, especially in reference to the so-called vegetative functions, both nutritive and reproductive. Thus, both are nourished from without, by processes of absorption and interstitial assimilation; in both the functions of secretion, excretion and respiration are observed; and a form of circulation is present in most animals and in some plants. In both the phenomena of growth take place; in both, existence is of limited duration; and, in both, the individual springs from a predecessor or parent, and in turn assists in reproducing new individuals or offspring.

Differences between Animals and Plants.—The distinction between animals and plants is easy, when attention is limited to the highest forms in each kingdom of organic nature; for no one can confound a tree with a quadruped. In general, the organs of animals are far more complex and numerous, and more specially devoted to particular purposes, than is the case in even the highest plants, the organs of which, as the leaves, are mere repetitions of the single leaf, or, as the sepals, petals, and even stamens, pistil, and parts of the fruit, are but modifications of the foliaceous organs. So also the tissues of animals are more numerous and more complex, and the animal functions more varied, than those of plants.

But at the lower end of the animal and vegetable series the borders of the two kingdoms become, as it were, conterminous, and the difficulty of placing in their proper category some of the lowest organized forms, infusorial and algaceous, has perplexed both zoologists and botanists. Besides this practical embarrassment in regard to mere classification, there exists a real difficulty in determining, by means of sharp definitions, the differential characters between animals and plants generally. The following distinctions, however, are those usually drawn.

First, animals generally possess sensation, consciousness, and volition, whilst plants are certainly destitute of volition and consciousness, and also of true sensation; but there are a few animals which have no volition, as the Spongida, and some perhaps which have no sensation, as the Gregarinida; again, there are many plants, the movements of which are to some extent adapted to certain purposes, though they are not volitional, such as the climbing plants, the sunflowers and others, which turn in obedience to light or other stimuli; and there are some, such as the sensitive plant, and the fly-catching plant, which possess a sort of excitability, suggestive of, though not attributable to, true sensibility in their leaves.

Secondly, motion, especially locomotion, is a great characteristic of animals; whilst plants, as a rule, are stationary. But there are certain animals which are fixed, such as the sessile Polyzoa, Cirrhopods, Actinozoa, Infusoria, and Spongida; and there are plants, such as the Centaurea and Berberis, which manifest a true contractility of tissue, and specific motions in their stamens; other plants, such as the Chara and Vallisneria, exhibit remarkable movements in the contents of their cells; whilst many of the forms among the minute Algæ manifest active locomotion, such as the Volvox, Oscillatoria, Zygnema, and certain Monads. Whether such movements in plants are due to other causes than contractility is not known; a proper contractile tissue is certainly more markedly developed in animals, existing even in the lowest forms, such as the Rhizopoda and Spongida.

Thirdly, there are certain differences between animals and plants, as regards their food, and its mode of preparation, before it is absorbed. Thus, animals being locomotive, usually seek their food, whilst plants, being fixed, find their food at the spot which they inhabit. But there are sessile or fixed animals, and, amongst the Algæ, moving plants. Animals usually feed periodically, or at certain intervals; but plants much more continuously. The food of animals is both solid and fluid, and the solid portions require to be dissolved by a digestive process, previously to being absorbed; the food of plants is always presented to them already in a state of solution. Animals, as a rule, receive their food into a mouth leading to a distinct stomach, or into some other internal permanent cavity, as in the Infusoria, or into a temporary cavity only, as in the Amœba and Actinophrys; whilst plants have no stomach or digestive cavity at all, but absorb their food directly at some part of their surface. But even this obvious distinction is not universal, the lowest Protozoa, viz., the Gregarinida, not possessing a stomach, or even a temporary digestive cavity.

The chief point of distinction between the food of animals and plants, relates to its source and chemical composition; and this constitutes a more positive ground of distinction between them. Animals require food already prepared by some pre-existing organism; that is to say, food composed of certain proximate constituents named organic substances, because they are the result of chemical combinations at present only known to occur in the living bodies of animals or plants. Animals, therefore, feed upon either animal or vegetable matter, *i. e.*, on organic substances. But plants feed exclusively on inorganic substances, derived from the atmosphere, the water, and the soil. The chemical composition of the organic food of animals, for they too require air, water, and certain mineral constituents, is highly complex, consisting of the quinary substances known as albuminoid bodies, or their immediate derivatives, besides the carbhydrates, starch, and sugar, and the hydrocarbons, or fatty substances, all of which are reduced to a state of minute division, or solution, by special digestive processes, and are then assimilated. These substances are obtained, in the case of carnivorous animals, from other animals; in the case of the Herbivora, from plants; in the case of the Omnivora, from both sources; ultimately they are always derived from the vegetable kingdom. On the other hand, the food of plants, in addition to the necessary saline mineral constituents, consists of carbonic acid, water, and ammonia, which binary chemical compounds they, by aid of their vito-chemical processes, stimulated by light and heat, combine into the carbhydrates, to form starch, sugar, gum, and woody fibre, the hydrocarbonaceous oils, and the quaternary and quinary nitrogenous albuminoid bodies, such as thein, legumin, and gluten. Plants, therefore, appear to have the power of forming, as the highest product of their vital processes, from carbonic acid, water, ammonia, and sulphur, albuminoid matter—a power not possessed by animals. Plants also directly form the carbhydrates, and probably from these, the hydrocarbons; whilst if animals produce these bodies, it is supposed to be from the decomposition of albuminoid substances. It has been noted that the organic acids and bases formed in animals, are much fewer than those met with in plants, and that but a small number are common to both kingdoms.

Lastly, the nature of the chemical processes which occur in the economy of animals and plants, must necessarily differ, in accordance with the difference in their respective food. In animals, the organic constituents of the food once digested, absorbed, and assimilated, undergo, under the influence of a certain temperature, many changes, the tendency of all of which may be expressed by the term *oxidation*, oxygen, derived from without, being largely concerned in those changes, and the ultimate products being, when such changes are completed, chiefly water, carbonic acid, ammonia, and sulphates. The whole of these changes are *analytic*. In plants, the inorganic constituents of the food—water, carbonic acid, ammonia, and sulphates—once absorbed, also undergo, under the influence of light, many changes; the characteristic of which is *deoxidation*, oxygen being given off in the process, which may be characterized as *synthetic*. Plants, therefore, build up from the dead or inorganic world, the organic materials of their own fabric, and also those which alone can be converted into the substance of animals; whilst these latter restore to the inorganic world the chemical elements which have passed in succession through the living tissues of both plants and animals. In this way, indeed, the balance between the two great subdivisions of the organic kingdom is maintained, and the continued existence of both insured. The germinating embryos, and the flowering parts of plants, however, give off carbonic acid; and so do all the parts of plants, during the absence of light; not, as may be suggested, in consequence of a process of oxidation, but because the carbonic acid, which then enters them as food, is no longer decomposed. It is also generally alleged that parasitic and other fungi absorb carbonic acid and give off oxygen, both during day and night; but, as regards the daytime, this is doubted by some.

In conclusion, the broad distinctions between animals and plants, consist in the possession, by the former, of true sensibility, consciousness, and volition; in the further possession of a stomach; in their inability to form albuminoid compounds, or other organic substances, directly from inorganic materials; and lastly, in their absorption of oxygen, and evolution of carbonic acid. On the other hand, plants are destitute of volition, consciousness, and true sensation; have no stomach; can form albuminoid and other organic compounds from inorganic matter; absorb and fix carbon, and give off oxygen. Lastly, it may be mentioned that, as a rule, animals, in accordance with their higher functions, possess not only more complex organs, but a much larger number of component tissues.

The form and structure of any microscopic organized body, will usually suffice to decide its proper position in the one or the other of the two organic kingdoms of nature, provided only that it be in its fully developed condition; but in regard to germs, whether ova or spores, it is difficult, and sometimes impossible, to arrive at a conclusion.

RELATIONS OF THE ORGANIC WITH THE INORGANIC KINGDOM OF NATURE, OR OF ANIMALS AND PLANTS WITH MINERALS.

Plants, and animals, including man, which compose the organic world, are distinguished from the inorganic world by their manifestation of "life." The Linnæan definition, "Lapides crescunt, Vegetabilia crescunt et vivunt, Animalia crescunt, vivunt et sentiunt," *i. e.*, "Stones grow, Plants grow and live, Animals grow, live, and feel," also expresses, though imperfectly, the distinctions between the organic and inorganic kingdoms of nature; for mineral substances simply increase or grow by *accretion*, plants and animals grow by means of *living* processes, whilst animals surpass plants by possessing *sensibility*. A closer inspection of the characters of organic and inorganic bodies reveals, however, a series of important differences, not only in their form and size, but more especially in their chemical characters, their structure, the nature of the actions which take place within them, their mode of formation, maintenance, and increase, their duration, and their manner of production, or reproduction.

The *form* of organic bodies is always determinate; that of some inorganic bodies, such as crystals, is likewise determinate, but this is not an essential characteristic, the greater number of them being irregular in form. Organic bodies do not present strictly geometrical forms, and have more or less curved outlines and surfaces; whilst, as a rule, inorganic bodies, when of determinate shape, have geometrical forms, plane surfaces, and straight outlines; but there are a few exceptions of crystals having curved surfaces, viz., the diamond, dolomite, and spathic iron; and inanimate matter sometimes presents a tendency to assume a more or less spheroidal shape. The simplest forms of organic bodies present a universal tendency to a spheroidal, oval, or ovoid shape; but linear forms prevail in the more highly developed species; ramification and repetition of parts are common, and very frequently spiral forms are seen, either in parts or in entire organisms. A bilateral symmetry is likewise almost always apparent; though this also is met with in the inorganic crystalline bodies. The irregularly formed inorganic bodies have irregular surfaces, and are without symmetry.

In *size*, organic bodies are determinate, each species within certain dimensions. Inorganic bodies having crystalline forms, are also limited in size, but they exhibit wider individual deviations in this respect; whilst the non-crystalline inorganic bodies have no determinate bulk.

Organic bodies contain no *chemical elements* beyond those which are found in the inorganic world; but the total number of elements contained in all the organic compounds, is fewer than that of those contained in the mineral kingdom. Organic bodies present a striking uniformity of composition; most of them being ternary, consisting of carbon, hydrogen, and oxygen; a certain number quaternary, containing, in addition, nitrogen; and a few only, absolutely essential to organization, quinary, containing likewise sulphur or iron. Inorganic bodies, on the other hand, exhibit a far greater variety in their component elements; they also present a greater variety in their atomic constitution, being not only ternary, quaternary, or quinary, but frequently binary or simple.

The compound chemical substances contained in or derived from organized bodies, are named *organic* compounds, and are treated of in so-called *Organic Chemistry*. Their chemical constitution is more complex than that of inorganic substances, and their properties are more various. Though composed of but a few elements—chiefly, as already stated, of these four, carbon, hydrogen, oxygen, and nitrogen—they are characterized by the *high number of atoms* of those elements, which enter into their composition; so that, *e. g.*, whilst only one atom of carbon, or two of hydrogen, are combined with oxygen to form carbonic acid and water, no less than six atoms of carbon, twelve of hydrogen, and six of oxygen, enter into the formation of grape sugar. The *molecules* of organic substances, *i. e.*, the aggregate of all the atoms of each element which they contain, are therefore *larger* than the molecules of inorganic chemical compounds. In both organic and inorganic chemistry, certain *radicals* are supposed to enter into combination in fixed proportions, with some single element, such as oxygen, chlorine, or even a metal. In organic chemistry, such radicals are always *compound*, consisting themselves of two elements, as for example, cyanogen, which is a compound radical containing carbon and nitrogen; but such compound radicals also exist amongst inorganic bodies, as *e. g.*, cyanogen itself, when made synthetically from inorganic matter, and also ammonium, which is composed of hydrogen and nitrogen. Until comparatively recent times, a broad distinction was supposed to exist between all organic chemical compounds, or the substances immediately derived from their decomposition, and purely inorganic chemical substances, the former being believed to be alone producible by vital actions. But the distinction has, in regard to many substances at least, been completely effaced by the discoveries of Wöhler, and more especially by the labors of Berthelot and others. The former chemist first showed that urea is identical with cyanate of ammonia, which can be artificially produced, and hence is named artificial urea. Ammonia, formerly supposed to be producible only from the decomposition of previously organized matter, can now be obtained from inorganic materials, by first making carbon and nitrogen unite artificially, under the influence of carbonate of potash, to form cyanogen (in cyanide of potassium), which, decomposing with water, yields ammonia. Again, tartaric and oxalic, and some other organic acids, and even alcohol, have been made artificially by a series of synthetic steps, without the intervention of any vital process, or the employment of any organic substance, or the product of any previous vital action. Thus, acetylene (C_2H_2) is formed by electric sparks passed from carbon points through hydrogen gas; this acetylene is made to combine with copper, and then, when subjected further to the action of nascent hydrogen, produces ethylene (C_2H_4); the ethylene, united with sulphuric acid, forms a compound ($C_2H_4SO_4$), which, when diluted with water and distilled, gives off alcohol (C_2H_6O). It would therefore seem possible that other and higher so-called organic compounds, such as sugar, quinine, and even albumen, may hereafter be artificially produced from inorganic materials only. These researches already suffice to show that the *synthetic* actions, by which plants build up organic substances from inorganic elements, are similar in nature to those which have been devised by man; and that, accordingly, the chemical molecular attractions employed or operating in each, are identical. So, also, the *analytic* or decomposing processes of the chemist, are paralleled in the laboratory of the living organic world; for sugar in solution, at certain temperatures, under the influence of the yeast fungus, *Torula cerevisiæ* (supposed to be one form of the *Penicillium glaucum*), produces alcohol; at lower temperatures, under the action of the vinegar plant, Mother, or *Mycoderma aceti* (said to be another form of *Penicillium glaucum*), it yields acetic acid; and in the presence of *Oidium lactis* (likewise referred by some to the same fungus), lactic acid. These facts, moreover, furnish proof of the identity of the chemical force acting in the organic world, and that which is artificially set in operation by man.

Furthermore, organic bodies, with the large number of their atoms, and their complex molecular constitution, are extremely liable to *decomposition*, as exhibited in various ways; thus they are, for the most part, unstable or prone to putrefaction, though it must be admitted that there are likewise inorganic compounds of most unstable character. The action of heat on organic compounds is invariably completely destructive, their elements being resolved into other and simpler compounds, such as the products of destructive distillation or decomposition, which, on the withdrawal of heat, do not reunite to form the original complex organic substance; wood, *e.g.*, gives, by distillation, tar, methylic alcohol, benzole, acetone, acetic acid, and certain gaseous substances; and, if completely burnt, yields carbonic acid and water, which substances do not reunite to form wood. Most inorganic bodies are comparatively stable, and do not undergo putrefaction; moreover, though always changed in condition, and frequently decomposed, when subjected to the action of elevated temperatures, they may, and often do, relapse into their original state when the temperature is again lowered.

Organic bodies are still further, and more distinctly, characterized by their *structure*, which is always heterogeneous. Thus, organic bodies are composed of different parts named organs and tissues, each bearing a certain relation to the rest, having peculiar uses, and consisting of a mixture of solid, fluid, and even gaseous materials, and not exclusively of one or other condition or kind of matter; the solids serve to support and hold together the organs or tissues, and to contain the fluid parts; whilst the fluid parts, which hold the gases in solution, are necessary for the diffusion of nutritive materials amongst the solids. The organs and tissues themselves are not homogeneous, but also consist of organic structural elements, frequently of the so-called vesicular, or naked, nucleated cells, and other parts, exhibiting minute but regular and definite details of structure, the whole being usually inclosed in a general investment. The simplest animals and plants, and the animal germs and vegetable spores, likewise exhibit such definite structure, consisting, as we have seen, either of cystoplasts or gymnoplasts, *i. e.*, of vesicular or naked nucleated cells. Even simple nuclei, and the primitive protoplasm, consist of elementary granules.

It is necessary to admit that this definite cell-structure, which is the characteristic of obvious "organization," and perhaps also the formation of protoplastic nuclei and granules, are not merely necessary conditions of "life" or "vital action," but are themselves products of such action, assimilative and formative, metabolic and metamorphic.

Without such organic vital action, perhaps the development of organizable substance is not conceivable, certainly not that of organized structure; and hence it is, that the mind is driven to the assumption or inference that some peculiar force, superadded to the inorganic forces of nature, is here in action. Now, inorganic bodies have no such structure; not even a crystal exhibits it when examined by the eye or by the microscope; its substance, even to the minutest molecule, is homogeneous, although a few examples occur of crystallized bodies, such as ice, having minute drops of fluid or gaseous matter confined in little chasms in their interior. But inorganic bodies, generally are composed either of solid, liquid, or aeriform matter, the particles of which are simply held together or are intermingled.

The heterogeneous composition or structure of organic bodies, as compared with the homogeneous substance of the molecules of inorganic bodies of the most regular form, such as crystals, is connected with the tendency and necessity of the former, during their life, to undergo ceaseless *internal motion*, and constant *change;* whilst the latter, when once formed, may remain unchanged for an indefinite period of time. The inmost substance of an organic body continually suffers those changes—changes of absorption and assimilation of new material, and removal of old material—which constitutes the very essence of vital action; whilst the material of an inorganic body, so long as it preserves its individuality, continues unaltered. An organic body is nourished and grows; an inorganic body merely increases in size. The nutrition and growth of an organic body, are accomplished by an interstitial process of waste and repair, and by evolution of new elementary parts, both processes depending upon a deposit and accretion of new selected material around or within each elementary constituent of its organized structure, or, as it has been said, by intussusception; whilst, on the other hand, the inorganic body, whether crystalline or non-crystalline, simply increases by the juxtaposition or superaddition of like matter upon its surface, *i. e.*, by an accretion to its general or external surface only.

Organic bodies possess, in their perfect condition, powers which are only called into activity by stimuli, under the influence of which they react, as in the case of the germ, or seed. These powers do not last indefinitely; but they may remain dormant for a long period, even for thousands of years, in the case of seeds, without being extinguished. Inorganic bodies retain their own properties, however, for indefinite periods.

Organic bodies, manifesting life, are subject to the conditions of health and disease. Moreover, their *duration* is limited; the individual animal or plant, however complex, or however simple, ultimately dies; whilst inorganic bodies either remain unchanged, enduring indefinitely, or, if they undergo decomposition, it is in order that their elements may assume conditions of more perfect stability.

To maintain the continued presence, on the earth, of organic bodies, which, subject as they are to individual death, have a limited duration, the *reproduction* of the species is provided for. Hence the last characteristic of organic bodies, as compared with inorganic, is this:

that they are all derived from previously existing parents or stocks, by ova, germs, gemmules, buds, seeds, or spores. Spontaneous generation, which will be hereafter discussed, has not yet been proved to occur in regard to any organic body, animal or vegetable. Organic bodies go through a cycle of changes, both of form and composition. They are nourished, grow, and are continually changing their substance and shape; they attain perfection, give rise to new individuals like themselves, and then die. No such cycle of change and reproduction is observed in regard to any inorganic body.

SPECIAL PHYSIOLOGY.

THE ANIMAL FUNCTIONS.

THESE, as already explained, are Motion; Sensation, common and special; the Regulation of Movement; and the higher Psychical functions.

MOTION.

All power of intrinsic self-movement, or spontaneous action, in man and animals, depends either on muscular contractility, that particular form of contractility possessed by a specially organized tissue, the muscular tissue, or the so-called ciliary motion exhibited by the minute vibrating organs called cilia, or on the less common and obvious actions of contractile sarcodous cells, or still simpler masses of protoplasm. General movements are impressed on living animal bodies as well as on dead ones, by the force of gravitation, and these movements enter, as it were, into their various locomotive or other acts, especially in progression, whether this be terrestrial, aquatic, or aerial. Gravitation also influences the special movements of the limbs and other parts of the living body.

The physical force resulting from the recoil of the yellow elastic tissue, which is so frequently employed in the animal economy, likewise assists in the intrinsic movements of many parts; but this tissue cannot properly be regarded as an original source of motion, for it must first be extended before it can act, and this extension is accomplished either by gravity or by muscular effort.

There likewise occur in certain fluids and tissues of the body, when examined under the microscope, movements of a tremulous character, named *molecular movements*, as in the fine particles or molecular basis of the chyle, in pigment granules suspended in fluid, or in these or other minute granules contained in the interior of cells. These movements are purely physical, and may be observed with the microscope in any very minute particles of dead matter sufficiently light to float in a fluid.

Still more recondite molar and molecular movements, of a physical and chemical kind, occur in the transference of dissolved material by osmosis and dialysis through the body; in the transmission of sensory and motor impressions along the nervous substance; in the passage of electrical currents through the tissues; and, lastly, in the intimate and incessant changes of nutrition. These movements, thus grouped together, are vito-chemical or vito-physical; and belong to a class in which perhaps, hereafter, even muscular, ciliary, sarcodic and protoplasmic movements will find their place and affinities.

MUSCULAR CONTRACTILITY.

Contractility, speaking generally, is, as we have seen, that property by which a living tissue is capable of shrinking in certain directions, so as to undergo a spontaneous change of form. The muscular *contractility*, muscular *irritability*, *vis musculosa*, or *vis insita*, is possessed by all the forms of muscular tissue, viz., the striped muscular fibre, the plain or unstriped fibre, and the contractile fibre-cells. This most important vital property, when called into play, produces *muscular contraction*, which does not consist of a shrinking, condensation or contraction of the tissue in all directions, such as is undergone by a mass of iron in cooling, but of an approximation of the particles in some definite direction, viz., in that of the length of the fibre or fibre-cells. Hence the fibre or fibre-cell, whilst it shortens itself, always increases in thickness.

Contractility is distinguished from mere elasticity by the fact that it is a property of a living tissue only, *i. e.*, a vital property, whilst elasticity is a physical property which persists in a tissue after death until decomposition or desiccation destroys it. Moreover, elasticity merely requires for its exercise that the elastic part should be previously extended, whereas contractility demands the agency of some external exciting cause or influence, which is called a *stimulus*. Hence the term muscular *excitability* occasionally used.

The *stimuli* capable of exciting the property of muscular contractility are very various. Some are mechanical, such as a weight, a blow, or a scratch with a pointed instrument, or even a sharp knock on a muscle in the living body; heat or cold, especially sudden changes of temperature, also act as stimuli; the chemical stimuli are acids, alkalies, or mineral salts; vegetable irritants also act, such as mustard; electrical stimuli, such as the galvanic current and electrical shocks; and, lastly, the vital stimuli, originating in or acting through the nervous system, such as the reflex, emotional, ideational and volitional stimuli. It is by means of these vital stimuli that the muscular tissues are most frequently excited to contract in the living body.

These stimuli may be applied either directly to the muscles, or indirectly through the nerves; thus, when the prepared hind-limb of a frog is so removed from the body, that a portion of the sciatic nerve, in an uninjured state, projects from its upper end, a mechanical, chemical, or electrical stimulus may be applied either directly to the muscles, and will make them contract, or they may be applied indirectly to the projecting nerve, with the same, and even with more striking effect, so long as the nerve retains its own vital properties. In the former case, the contraction is named *idio-muscular;* in the latter, *neuro-muscular.* The nerve itself is said to conduct the stimulus to the muscle; but, as we shall hereafter see, the nerve is probably excited by the stimulus, a certain change takes place in it, and this change is propagated along the nerve. Even in the so-called direct stimulation of a muscle, the nerves contained within it may be concerned, so as to constitute that also a case of indirect stimulation.

Certain chemical stimuli, such as alkaline solutions, act equally well, if applied either to the muscle or to the nerve; some, such as alcohol, creasote, and lactic acid, act almost solely through the nerves; whilst others, as sulphate of copper and ammonia, operate powerfully and almost exclusively on the muscle, but hardly at all through the nerve. Over-stimulation, as, for example, repeated electrical and powerful discharges, temporarily destroys the contractility. So likewise portions of muscle subjected to extreme weight lose their contractility. Moderate, but numerous and rapid, electric shocks produce a state of continuous contraction, known as *tetanus;* in the frog, at least 15 shocks per second are necessary to tetanize the muscles; with about 100 shocks per second the tetanus ceases, but it is again induced by increasing the strength of the current. A uniform continuous current does not maintain the original amount of contraction, the muscle gradually lengthening again somewhat. A muscle exhausted by long-continued stimulation, recovers its contractility after sufficient rest; this is also true of muscles recently separated from the body. But in atrophied muscles, in which the transverse striæ are destroyed, and the whole fibre filled with fat particles (fatty degeneration), there is no contractile power remaining.

The phenomena which characterize muscular contraction, have been chiefly studied in the striped muscular fibres of animal life. The act of contraction usually begins at either end of a fibre, but often at one or more intermediate spots. When a single fibre undergoes contraction, a slightly darker spot first appears at some point of its border; this spreads across the whole diameter of the muscle, and, on careful examination, it is seen that the transverse striæ become finer, and are drawn closer together, becoming twice or even four times as close as in the relaxed fibre; this action, the limits of which are well defined, then continues to spread each way through the fibre, by a wave-like progression, parts of the fibre becoming contracted, whilst other parts are assuming a relaxed form. The changes thus described, and the accompanying approximation of the transverse striæ, appear to be due to a corresponding shortening of all the component fibrils of a single fibre, and the general result is a shortening of the whole fibre, which, at the same time, becomes thicker in its contracting portions. Supposing the ends of the fibre to be free, it still continues soft and flexible; but when muscular fibres, as in a perfect muscle, are attached at their two ends, then their substance becomes firm and hard, as may be felt during the contraction of a living muscle in the arm. This increased firmness is due to increased tension of the fibres, and does not imply, as might at first be supposed, any important condensation of the muscular substance; for experiments show that this is very slight, if it occurs at all. Thus, the arm of a man has been inclosed in a glass cylinder having a narrow upright glass tube connected with it, the part of the cylinder not occupied by the arm being filled with water (Glisson); again, the prepared hind-limb or limbs of frogs, have been suspended in a bottle of water, provided with an upright capillary tube connected with its neck (Sharpey, Weber, Valentin, and others). The muscles of the arm have been then brought into play, or, the muscles of the frog's limbs have been excited to contract by electrical currents passed into them along wires properly fixed for that purpose; and any change in their bulk, indicated by a fall in the level of the water in the upright tubes, has been noted. By most observers (Prevost, Dumas, Matteuci, Sharpey), it is stated that no diminution of bulk occurs under such circumstances, but according to Ermann, Weber, and Valentin, a diminution, scarcely perceptible in careful experiments, amounting only to from $\frac{1}{13000}$ to $\frac{1}{10000}$ of the bulk of the contracting muscles, takes place.

When a muscular fibre relaxes it resumes its previous length, and at the same time diminishes in thickness; and if its points of attachment remain stationary, or at the same distance from each other, the fibre is thrown necessarily into zigzag flexions, specially noticed by Prevost and Dumas, and at first erroneously supposed to be produced in the *active* state of the muscle, and to account for its shortenings. During contraction the sarcolemma of each fibre is passive, and is either thrown into minute folds, or else displays a feeble elasticity. The contractile property, indeed, resides entirely in the sarcode, or peculiar fibrillar contents of the tube of the sarcolemma.

According to Helmholz, the contraction of a muscle is not instantaneous, but a certain interval of time, about $\frac{1}{100}$th to $\frac{1}{50}$th of a second, elapses between its stimulation by electricity, and its actual contraction; this he names the period of *latent contraction* or *excitation.* The muscle at first contracts quickly, then more slowly; and it takes a longer time when powerful contractions are excited. The *velocity* of the wave of contraction in the frog's muscle is about forty inches per second (Aby). The rate of motion along any particular muscular fibre is such, therefore, that its contraction may be regarded as almost simultaneous from one end to the other. But there is reason to suppose that in any given muscle, certain fibres are undergoing contraction whilst others are at rest, an alternation of labor which would enable a muscle to maintain a longer effort with less exhaustion or fatigue.

The amount of contraction which occurs in a detached frog's muscle is, according to Weber, from 50 to 60, or even 80 per cent. of its length; that is to say, the muscle shortens to one-half, or even to one-fifth, of its length. In the living animal and man, owing to the resistance of antagonistic muscles, and to the structure of the joints, the muscles shorten themselves only about one-third of their length.

In the frog's muscle the maximum amount of shortening takes place when the contraction is sudden, when the muscles are not fatigued by previous stimulation, and when the resistance offered by weights appended to them is slight.

The striped and unstriped muscular fibres present certain *peculiarities* in their action, and so do the muscles of the heart. Thus, when the heart is artificially excited at any one point, a rapid and powerful contraction of a large part of its walls ensues, quickly followed by relaxation, and then by a succession of contractions and relaxations. When similarly excited, the unstriped muscular tissue of the intestines contracts more slowly, but more permanently. In non-striated muscles generally, the contractions induced by electrical discharges are partial or local, slowly induced, sometimes interrupted, and last after the stimulus is removed; but, in the striated muscles, rigid, general contractions quickly occur, continue so long as the stimulus is applied, and cease suddenly on its withdrawal. Contractions, induced indirectly through the nerve-trunks, are more sudden, general, and energetic than those occasioned by direct stimulation of the muscle. Some involuntary muscular fibres are more easily and powerfully excited than others, as, for example, those of the intestines, as compared with those of the gall-bladder and the ureters, even cold air being sufficient to induce contractions in them. The peculiarities now described are manifested also in the ordinary actions of the different kinds of muscular tissue during life. Thus the voluntary striped muscular tissues act suddenly, powerfully, and in effective combination, whilst the plain involuntary muscles contract much more slowly, partially, and feebly; as witness the quick, general, and energetic movements of the limbs, fingers, tongue, and eyelids, as compared with the slower, more local, and weaker movements of the muscular coat of the stomach and intestines. In the latter organs the degree of contraction is likewise about one-third. The contraction also presents a great peculiarity, viz., that of being propagated onwards, or travelling along successive portions of the alimentary canal, by what is called *vermicular* or *peristaltic* action. It is, moreover, in these and other cases, excited by the contents of the muscular canals. In the heart of man and the higher animals, the imperfectly striated muscle, probably from some peculiarity of its nerves, contracts repeatedly, in regular and continuous order, alternating with certain periods of repose: this is called *rhythmic* contraction. It is observed also in the lymphatic hearts of the frog, and in the hearts or dorsal vessels of the lower animals.

The *force* with which a voluntary muscle contracts, is very great, much greater than the mechanical resistance offered by a dead muscle. It is equal to the lifting, through a minute distance, of a mass sixteen to seventeen thousand times its own weight; but as the distance is increased, the weight lifted is diminished. This force is exerted more favorably at the commencement of contraction, and gradually diminishes to zero, as the muscle shortens to its extreme degree. The *amount of force* depends on the *number* of the contracting fibres, whilst the *degree of shortening* depends on the *length* of those fibres.

In order that a muscle should act properly, its temperature must be at a due elevation, its supply of blood must be sufficient in quantity and of proper quality, and its nutrition amply provided for in the intervals of contraction. Arterial blood is essential to the healthy maintenance of muscular contractility. If the muscles be subjected to excessive heat, or be exposed to extreme cold, they will be in the former case exhausted, and in the latter benumbed. If the artery supplying a muscle, or set of muscles, be tied, their contractile power is destroyed; and if the blood be venous, or charged with carbonic acid, it will impair or destroy their irritability.

When a muscle ceases to act, it relaxes, or again elongates more or less, according to the position of the bones to which its ends are attached; and muscles evidently possess a certain amount of *flexibility* and *elasticity*, or *resilient power*, to adapt them to the changing positions of the limbs at the joints, and to the various conditions of length rendered necessary by those changes, even when the muscular fibres are in a state of inaction. The elasticity of muscular tissue is, however, very slight, and it diminishes during contraction. It would seem to be much greater, but much less perfect in its action, in the dead than in the living muscle. Thus, a dead muscle requires a greater force to stretch it, but, unlike a living muscle, does not return to its original length when the force is removed. A living portion of muscle undergoes an extension or elongation, when a certain weight is appended to it; the amount of elongation with moderate weights, is proportioned to the weight, but, with greater weights, the effect is no longer proportional; in dead muscle, and also in paralyzed muscles, the relative elongation is less. The physical *cohesive power*, or absolute strength of muscular tissue, increases up to the adult condition, and then diminishes. It is said to be greater during the so-called rigor mortis, but it decreases some time after death, when the muscles tear more easily.

After a muscle has contracted a certain number of times, a sense of fatigue or exhaustion is experienced in it,—a sensation which must be transmitted to the sensorium through the special sensory nerves of the muscle. It is these nerves also which must convey to the mind accurate information concerning the condition of the muscle, and the amount of effort which it puts forth in any particular action. It is also by these nerves that the impressions which cause the sense of pain in cramps, or other morbid conditions of muscle, are conveyed to the brain. That kind of sensation, which informs us of the amount of action in a muscle, is called the *muscular sense;* it is by this that we judge of different weights, and are able to maintain continued muscular effort. The other muscular sensations are probably only modifications of this sense.

When a muscle is quite fatigued, it requires rest or repose for the recovery of its exhausted irritability. Excessive exercise of a muscle, with due intermediate intervals of rest, increases, not only its contractile power and facility of action, but also tends sooner or later to an over-nutrition and increased development of its bulk, or *hypertrophy*, probably, as is supposed, from an increase in the size of its individual fibres, and not by the addition of new ones. If, on the other hand, a muscle be not sufficiently exercised, it falls in a state of *atrophy*, or wasting, or even undergoes a fatty change in its fibres, the striæ of which disappear; in either case, its contractile force is diminished and ultimately lost. The same changes and loss of irritability take place in chronic paralysis. There is a particular condition or state of slight tension of healthy muscles, which, beyond their mere elasticity, accounts for their retraction when they are cut across, and which is named their *tonicity*, or *tonic state*. It is persistent only so long as they are healthy, and remain in connection with the nerves and nervous centres; for if the nerves are cut, or if the nervous centres in connection with them are destroyed, the muscles lose their tone and become flaccid. It is this property continually in action, which serves, more than the elasticity already alluded to, to keep antagonistic muscles in a due state of equilibrium, in varying positions of the limb; it seems also to be by a powerfully-exercised tonicity that sphincter muscles, like that placed around the outlet of the alimentary canal, are kept contracted.

The muscular contractility is not extinguished immediately after death, but is retained for different periods by different muscles, and in different animals. For example, in the cold-blooded vertebrata, the reptiles, frogs, and fishes, it may last for many hours, or even for days; a turtle's heart has been known to beat three days after the death of the animal. In warm-blooded vertebrata, man, quadrupeds, and birds, the irritability ceases a few hours after death, soonest of all in birds. The irritability lasts longer in animals just born, and in hibernating animals killed in the winter during their sleep. The more active the respiration, the more active the muscular irritability; but the more dependent also is this irritability upon the respiratory process, and hence its speedier extinction in animals the respiration of which is active, and its longer duration in those the respiratory changes of which are of a feebler character. In the human body the irritability lasts longer in certain muscular parts than in others; it disappears first in the left ventricle of the heart, then, in succession, in the intestines, stomach, urinary bladder, and right ventricle of the heart, in all which parts it is lost before the expiration of an hour. It afterwards expires in the voluntary muscles, first in the trunk, then in the lower limbs, and lastly in the upper limbs. It continues still later in the left auricle, and latest of all in the right auricle of the heart, the *ultimum moriens* of Galen. It is totally lost within seventeen hours after death. The contractility is said to be destroyed, sometimes immediately, in cases of death by lightning, or by violent injuries to the nervous centres. It disappears only in cases of poisoning by carbonic acid gas or sulphuretted hydrogen. Cold air or water, and narcotic agents, taken internally, are said to hasten its departure. Narcotic solutions, morphia, cyanide and other salts of potassium, and the upas poison injected into the blood, also lessen or destroy it, and much more rapidly and effectively when directly applied to the muscles, though not necessarily when applied only to the nerves. Immersed in sulphurous acid, hydrogen, carbonic oxide, and carbonic acid gases, the muscles lose their contractility partly or entirely. Venous blood, which contains much carbonic acid, acts as a poison, lessening their irritability; whilst oxygen and arterial blood preserve it, and the latter, defibrinated and injected into a limb recently dead, will even restore the irritability after it has been suspended. Contractility, as already stated, is wholly lost in atrophied muscle.

Phenomena accompanying Muscular Contraction.

Certain important phenomena accompany those changes of form and condition in the muscles, which constitute their so-called contraction. In the first place, there is a sound produced by the contraction of muscles, which may be easily heard by placing one finger so as to close the ear, resting the elbow upon a table, and then contracting the muscles of the fore-arm. This sound has been well compared to the rumbling noise of distant carriages, and is called the *muscular sound;* it is probably owing to the friction of the contracting fibres against each other; its vibrations are said to be from thirty-two to thirty-six per second.

Another phenomena accompanying muscular contraction is the *production of heat.* The fact may be shown by direct experiments with the thermometer; but the exact amount of elevation of temperature can be more accurately measured by means of a thermo-electric apparatus, of which the contracting muscle forms a part.

If a metal ring be made of a semicircle of copper wire, and of another of iron wire, soldered together at their ends, and if one of the points of junction be made hotter or colder than the other, then thermo-electric currents, *i. e.*, currents of electricity developed by heat, are produced in the compound metallic ring. By introducing a needle galvanometer in the circuit of the ring, the *direction* and *force* of such currents can be measured for each *degree of unequal temperature* in the two points of junction.

A needle galvanometer consists of a magnetized needle, suspended horizontally by a single fibre of silk, and placed *under cover of glass*, means being provided for passing a current of electricity in its neighborhood at will. A circular card or disc, marked with degrees, and fixed beneath the needle, accurately registers any movement which takes place in the latter.

Now, when a current of electricity is made to pass, in any definite direction, near such a magnetized needle, the latter is deflected, or turned to one side or the other; the wire through which the electrical current passes, itself acts like a magnet, and tends, by virtue of mutual attractions and repulsions, to cause the needle to stand at right angles to it. The direction of the deflection depends on the direction of the current, and the amount of deflection on the force of the current. If the observer looks down upon a galvanometer, with the north pole of the magnetized needle turned from him, and a current of electricity be passed along a neighboring wire, *above* the needle, also in a direction *from* him, the needle will deviate to the left hand; but if the current were passing *under* the needle in the same direction, the needle would deviate to the right hand. If the current passes *towards* the observer *above* the needle, the needle is deflected to the right, and if *below* it, to the left. Now it is obvious that if the wire, along which the current is made to pass, be bent into an oblong horizontal loop, within which the needle is suspended, so that the current passes *from the spectator above the needle*, and returns *towards him under it*, the force, which causes the needle to deflect towards the left hand, is doubled; because the departing current above the needle, and the returning current below it, have both a tendency to make the needle deflect in the same direction, *i. e.*, to the left. By covering, and so insulating the wire, and by multiplying its departing and returning bends, by coiling it up an immense number of times into the required oblong loop, within which the needle may be suspended, the deflecting force is still more powerfully increased; and in this way, with a coil of very fine wire, many thousands of yards, nay, even some miles in length, exceedingly feeble electrical currents can be detected, from their causing the deflection of a delicate and lightly-suspended magnetized needle. Such a needle, however, suspended singly, is subject to the magnetism of the earth, which would derange or arrest the operation of very feeble currents. Hence, to prevent this, another needle, of equal magnetic power, is suspended below the upper one, and attached to it by a rigid axis, having, however, its poles turned in the opposite directions, the north pole of one being under the south pole of the other, and *vice versa.* In this way the effects of terrestrial magnetism are neutralized and the needle is made *astatic* and ready to be impressed solely by such currents as may pass through the coil of wire within which it is suspended. Such an instrument is influenced by electrical currents of every kind, whether developed by friction, thermal influences, chemical, or vito-chemical action; the force of the current is always measurable in degrees upon the scale.

In order to apply the thermo-electric test to the measurement of heat developed in a living animal or man, a U-shaped piece of wire, composed half of iron and half of copper, joined together at the bend, is immersed in water of a *known temperature.* A needle, also half of iron and half of copper, is thrust through the tissues, and so adjusted that the point of junction lies in the part, the relative temperature of which has to be determined. The iron shank of the U-shaped wire is now connected with the iron end of the needle, and the copper shank of that wire with the copper end of the needle; but somewhere in the last-named connection the galvanometer is inserted. Any difference in temperature between the metallic junction immersed in the water, and that embedded in the living tissues to be examined, creates a current, either one way or the other, according to which junction is hotter than the other; and any elevation or fall of temperature in the one, such as might be produced by the acts of contraction and relaxation of a muscle, would cause proportionate, and measurable, changes in the strength of the electric current.

As thus determined, the quantity of heat evolved in contracting muscle in warm-blooded animals, has been found sufficient to raise its temperature by 1° or 2°; in the frog the elevation of temperature is rather less than ⅓°. This effect may be partly due to friction, but it is supposed to be chiefly owing to chemical combinations taking place in the muscle, incidental and essential to the act of contraction. Probably these chemical changes consist in an oxidation of the constituents of the muscular tissue; for exhausted muscle contains more creatin, creatinin, urea, and inosinic acid, than muscle in a state of rest (Helmholz); the substance of quiescent muscle is neutral; that of muscle, after frequent contractions, is acid (Du Bois-Reymond); the interchange of oxygen and carbonic acid is doubled in active muscle. It has recently been stated that the temperature of a muscle is *lowered* at the beginning of a contraction, but that, after a few seconds, a rise of its temperature takes place, which, in a tetanized muscle, continues after contraction has passed off. Such a lowering of temperature, if established, might indicate an absorption of heat, or an increase of the latent heat of the muscular substance during its commencing action; whilst the subsequent elevation of temperature might be due partly to increased chemical changes taking place after contraction had ceased, and partly to the greater activity of the capillary circulation. The amount of heat evolved is said to be proportionate to the work performed (Meyerstein and Thiry).

The living muscular tissue has also important *electrical* relations. Thus, it is a good conductor of electricity, and it is also extremely sensitive to that agent, being very easily excited to contraction by it.

Moreover, this tissue possesses within itself natural currents of electricity, which constitute what is called the *muscular current;* and, lastly, this normal current is more or less disturbed during the period of contraction of the muscle. Such currents are not peculiar to muscle, but are most marked in this tissue. Indeed, in all live muscles, when quiescent, in small portions of them, even in the minutest shreds which can be operated upon, electrical currents are constantly passing in certain definite directions. Their presence, their direction, and the disturbances to which they are liable, are detected, and determined, by means of extremely delicate galvanometers, constructed as just described.

For this purpose, it is not sufficient merely to place the pieces of muscle, or other tissue, between the ends of the very fine galvanometer wire, but special contrivances are needed to conduct the current from the soft tissue to the wire. In two glass vessels, Diagram A, containing a solution of common salt, are suspended by means of metal holders, *m*, supported on glass insulating rods, *g*, two pieces of platinum, *p*, which are connected respectively with the two ends of the galvanometer wire, *d*, *d*. Little cushions of blotting-paper, *b*, supported on small shelves in these vessels, but rising above their edge, also dip into the solution of salt; by absorption of some of the solution, they form two moist surfaces of contact, placed at a short distance from each other, upon which the piece of animal tissue experimented on can be laid, in any desired position, by means of a thin holder of glass. If the two moist cushions be first

Diagram A.

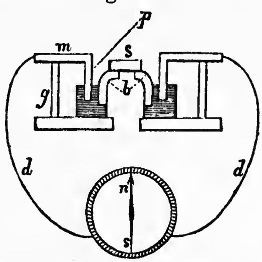

Diagram A (Vierordt). Apparatus for detecting the existence, direction, and strength of the normal electrical currents in animal tissues. *p*, one of the platinum plates, dipping into the solution of salt, contained in one of the glass cells; *m*, metallic connecting rod, supported on the non-conducting glass rod, *g*, and connected with the wire *d*, of the galvanometer. The same parts are seen on the other side. *b*, indicates two small cushions of blotting-paper which dip into the solution of salt; *s*, is another cushion moistened with the same solution, which, when placed on the cushions *b*, completes the galvanometer circuit; but no current passes, as there is no chemical action set up. If the cushion, *s*, be removed, and a piece of living muscle or nerve be put in its place, instantly a current is formed, and the needle of the galvanometer, *n*, *s*, moves to the right or to the left, and shows the direction and force of the current.

connected by means of a third cushion, *s*, moistened with the same fluid, the circuit is closed, but no currents are produced, the galvanometer needle *n*, *s*, remaining quiescent, and the whole apparatus being in a state of chemical and electrical equilibrium; but when they are connected by a piece of living animal tissue, Diagram B, then a portion of any currents, which may exist in the tissue, is instantaneously conducted through the lateral moist cushions, the saline solution, the platinum plates, and the wire of the galvanometer. The needle immediately deviates to the left, 1, 2, or to the right, according to the direction of the current; and the relative amount of deviation in either direction, indicates the strength of the passing current, and the changes producible in it. In such experiments, only a portion of the intrinsic currents of a tissue is diverted through the galvanometer, so that the total strength of such currents cannot be thus ascertained; but their relative electrical activity in particular tissues, under various conditions, may be determined.

The muscles of the Mammalia, including man, give very strong currents; but those of the frog are usually employed in experiments, as the currents in them are more persistent. An oblong piece of muscle is so prepared, that its longitudinal surfaces correspond with the sides of the muscular fibres, and its transverse sections with their ends. It is then placed, in various positions, Diagram B, 1, 2, 3, on the cushions of the apparatus just described, and the results on the galvanometer needle, *g*, are watched. When so placed, it is also made to contract, by any appropriate stimulus, and the effect on the galvanometer needle is recorded.

In a piece of living quiescent muscle, Diagram B, 1, 2, currents are found constantly passing from the longitudinal surface or section,

Diagram B.

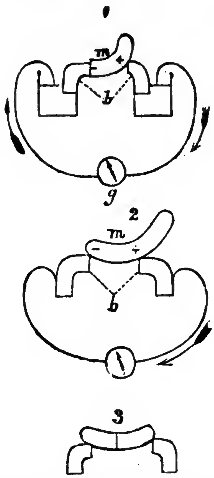

Diagram C.

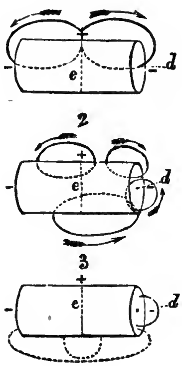

Diagram B (Vierordt). Views of pieces of muscle, *m*, placed on the cushions, *b*, of the preceding apparatus, in three different positions. In 1, the piece of muscle has its cut end in contact with one cushion, and its surface with the other; in 2, the piece of muscle has points at different distances from its centre or equator, touching the two cushions; in 3, the piece of muscle has points at equal distances from its equator in contact with the cushions, when no current passes.

Diagram C (Author) shows the direction of the normal muscular current, both within and without the piece of muscle. 1, 2, 3, three cylindrical pieces of muscular tissue; *d*, the axis or pole, and *e*, the equator of each piece. The black curved lines, with the arrows, in 1 and 2, show the direction of the muscular current outside the muscle, that is, as it would pass through the galvanometer circuit. The dotted curved lines show the path of the currents within the pieces of muscle. In 3, the dotted curved lines show lines of equilibrium, no current passing. In each piece, the signs + and —, show the electrical states of the equator and poles, or of the surface and ends.

through the galvanometer, *g*, to either transverse section, *i. e.*, from the sides to the two ends of its component fibres; so that the longitudinal surface or section of a muscle, or the sides of its fibres, are positive, +, and the transverse sections, or cut ends of the fibres, are negative, —. *Within the substance of the muscle*, however, the current passes from the cut ends to the lateral surfaces or sides.

A series of larger diagrams, Diagram C, will better serve to illustrate the course and character of these currents. The strongest currents are found to pass from the middle of the piece of muscle, which might be called its equator, 1, *e*, to the centre or axis, *d*, of both of its two cut extremities or poles. From points of the longitudinal surface more or less distant from the equator, to points of the ends more or less distant from the axis, the direction of the currents is still the same, but they are proportionally weaker, 2. When two points on the longitudinal surface, equidistant from the equator, are touched, 3, no current is evident, an equilibrium being established; but when two points unequally distant from the equator, are touched, 2, a feeble current is manifested from the nearer to the more distant point. In the same way, two points, at either cut end, equidistant from the axis, 3, give no apparent current; but if unequally distant from it, 2, they do.

To explain these remarkable electrical currents of the living muscular substance, it has been suggested by Du Bois-Reymond, that it possesses a peculiar electrical condition, which is supposed to be dependent on a special electrical polarity of the component molecules or the disdiaclasts of the sarcous elements. Each molecule, in a given longitudinal row, Diagram D, is imagined to have its equatorial or central part positive, +, and its two ends, or poles, opposed to the neighboring molecules, negative, —. In this case, a current would pass *outside* the molecules, from the equator to the poles, but, *within*

Diagram D.

Diagram D (Du Bois-Reymond) shows the theoretical electrical condition of the molecules of muscular tissue. Each molecule in a series, is supposed to be peripolar, the adjacent ends or poles being negative or minus —; and the central or equatorial part, positive or plus +. The plus portion is shown white and is marked +; the minus parts are left black, and are marked —. The arrows show the necessary directions of the normal currents outside such an arrangement.

the molecules, from the poles to the equator. Each molecule, in such case, would represent, in miniature, the electrical condition of the entire piece of muscle. This supposed condition of the molecules is named a *peripolar* electrical state. It exists in an artificial molecule made with a zinc equator and copper ends or poles, when immersed in dilute acid.

The muscular current in amputated limbs, also passes from the side of the limb to the cut extremity. It is manifested, as already mentioned, in even the smallest fragments of muscle, and also in the fibres of the heart, and in the non-striated muscular tissues. It remains for a time, though weaker, even when the contractility has already disappeared. In an entire muscle, the ends of which are not cut, it is stated by Du Bois-Reymond, that the currents have still the same direction, passing outside the muscle, through the galvanometer, from the sides or *natural* longitudinal surface, to the ends or tendons, or natural transverse surfaces of the muscle. In entire limbs, the current supposed to be the *resultant* of the combined currents of the several muscles, runs, in the case of the frog, from the tips of the toes to the trunk, and, in the case of the entire body, from the coccyx to the head; this is the so-called *total current* observed by Nobili. It is remarkable that the direction of the total current in the Mammalia has the reverse direction, *i. e.*, from the head downwards.

It is further stated by Budge that, in the sartorius muscle of the frog, he found two currents; one, the so-called *natural* current, passing *in* the muscle, from its lower to its upper end, and the other, corresponding in all respects with that described by Du Bois-Reymond, which he names the *artificial* current, and which he says is present in muscles only after a transverse section has been made through them. The natural current, being always in one direction, whilst the artificial currents pass within the muscle, from the cut ends to the equator, it follows that the former strengthens the latter in the lower half, but opposes and weakens them in the upper half of the muscle. Budge enters into other details, which cannot here be described. The subject is yet open to much further inquiry.

Portions of nerve, as we shall hereafter see, exhibit precisely similar currents to those found in muscle, and these follow the same directions, though they are weaker and more difficult of detection. So likewise pieces of brain and spinal cord, give similar currents. Other parts, such as the lungs, liver, and kidneys, offer either very slight or no currents. In the frog's skin a current is developed, which is opposite to that of the muscle; for the section of the skin is positive, whilst the surface is negative.

The exact cause of the electric currents, present in living muscular and other tissues, is not understood. They are doubtless, in some way, connected with the constant molecular chemical changes of combustion or oxidation, which occur in the nutrition of the living tissues,—with those incessant changes, indeed, which are characteristic of life, and without which there is no life. But it is unknown whether such chemical changes are the consequences of the electric currents, *i. e.*, are electrolytic; or whether, as this seems more probable, the currents themselves are the necessary accompaniments of the chemical changes. The nutritive molecular changes are doubtless more active in muscle than in nerve, and probably more so in nerves than in the skin; the strength of the electric currents obeys the same order. It is possible also that the nutritive changes are more active on the surface or sides of the fibres than at their centres or cut ends when they are divided, *i. e.*, that they are more active on the surface of the fibres which is found to be positive, than on the parts which are negative.

The electrical current proper to, and constant in, healthy quiescent muscle, or the normal muscular current, is evidently disturbed by the contraction of the muscle. It was said by Matteuci to be reduced to zero, or even to be reversed in direction; but by Du Bois-Reymond it is considered merely to be diminished, the needle being first deflected, in an opposite direction, when the piece of muscle experimented on is made to contract, but ultimately being merely less deflected than when the muscle is at rest. This diminution of the muscular current takes place all the same, whether the muscle be excited to contract by means of a direct stimulus, or by means of a stimulus applied indirectly through the motor nerve; nor does the nature of the stimulus, whether it be mechanical, chemical, or electrical, influence the result. The electrical current used to excite the motor nerve, may be derived from the contraction of other muscles, as will hereafter be explained in describing the so-called rheoscopic frog's limb.

Cause of Muscular Contractility.

Various theories have been advanced as to the nature and cause of muscular contraction, but all may be dismissed as being unsatisfactory, and at present our real knowledge may be said to be limited to the phenomenon itself, and to certain of its conditions and accompaniments. Two very opposite general views have been, and are still, entertained by physiologists on this subject. According to *one view*, the muscular tissue owes its contractility to the nerves distributed to it, a certain force generated in the nerves being transferred, as it were, to the muscles, and so imparting to them their special irritability or contractile property. We have seen, indeed, that the muscular contractility may be excited through a nerve. In the living body, this is the ordinary mode of stimulation; and when the motor nerve of a muscle is divided, neither the will nor the so-called reflex nervous stimulus, both of which require that the nerves should be in connection with nerve centres, can any longer excite contractions in it. By irritating the portion of nerve connected with the muscle, movements can be excited, however, for a short time; but after a period, varying from four to eight days, this can no longer be accomplished, although the muscle may still be excited to contract by the direct stimulation of its fibres—a condition which may continue, though in a much less degree, for more than two months, but which at last is completely lost. This fact has been held to show that the contractility of muscle is not inherent, but is dependent upon, or derived from, the nerves still contained in it; for the separated muscle, though continuously nourished, does not retain its contractility for a lengthened period. But a muscle, so separated from the nervous centres, is not permanently well nourished; it becomes atrophied or wasted, its fibres lose their transverse striæ, and undergo a fatty degeneration, so that both its structure and properties are destroyed. Moreover, its power of being *directly* stimulated, lasts longer than that of being indirectly excited through the divided nerve, and the frequent continuous application of galvanism to such detached muscles, will prevent their atrophy, and at the same time preserve their contractility.

These, and many other, considerations serve, therefore, rather to support the *second* and opposite *view*, celebrated from having been that adopted by Haller, and now very generally entertained, viz., that the muscular irritability is a special property of the muscular tissue itself, and inherent in it, a *vis musculosa*, or *vis insita*. The following numerous facts and considerations are usually quoted, as supporting this important doctrine in physiology. Nerves possess no contractility, but muscular tissue always does. Very small and isolated portions of single muscular fibres are seen to contract under the microscope. A contractile tissue is found in minute unicellular animal organisms, in which no nerve-tissue has been shown to exist. Contractile tissues are met with even in certain plants, though these are believed to be absolutely destitute of a nervous system. Muscular contractions, it is alleged, will occur in the muscles of the embryos of animals, even whilst none can yet be excited by stimuli applied to the nerves. Subsequently to the division of its nerves, a muscle, provided that its nutrition is maintained, retains or recovers its power of contracting on the direct application of a stimulus, long after it ceases to act on the stimulation of the divided nerve. Chloroform and ether suspend the power of the nervous system over the muscles, so that stimuli applied to the nerves no longer excite muscular contraction, although the contractility of the muscle itself, as shown by direct stimulation of its fibres, yet remains, and although the effects on the sensory nerves lead us to infer that these reagents act quite up to the extremities of the motor nerves also. There exists, moreover, a special poison, the woorari or curare, which is said to have the power of destroying the vital properties of conductility of the nerves down to their finest extremities, and yet permits the muscles to retain their contractility on the application of a direct stimulus. Lastly, in the case of a muscle like the sartorius muscle of the frog, which is provided with a nerve distributed to its central part only, the muscle can be made to contract at its extremities, after the destruction of the nerve itself (Kühne).

The preceding facts certainly tend to show that the muscular irritability is inherent in the muscle, and independent of the nerve. But a further question arises, viz., whether, granting that the muscular irritability is a property inherent in muscle, is it ever excited, or is it capable of being excited directly, or can it only be so, through irritation applied indirectly to it through the nerves? The minute distribution of the finest non-medullated extremities of the nerves among the muscular fibres, and their intimate connection with them, render it impossible to separate the effect of a stimulus upon the one and the other, so as to be able to say that a stimulus has acted on the muscle only, and not also on the fine branches of nerves mixed up with, or distributed upon, its fibres. The two last-mentioned experiments, viz., that on the effects of the woorari poison, and that on the sartorius muscle of the frog, are maintained by some to have solved this question, and to have shown that the inherent power in muscle is capable of being directly excited, i. e., *idio-motorially*, without the intervention of even the minutest extremities of the nerve-fibres, as well as *neuromotorially*, or through the agency of the motor nerves.

As to the ultimate cause of muscular contraction, it is quite evident that the slight condensation, if any, which takes place in the tissue during contraction, is wholly insufficient to account for the latter phenomenon. It is certain only that the tendency of the sarcous elements or disdiaclasts to alter their shape by shortening or widening themselves, and so to approach each other in a definite direction, is the essential fact in this remarkable phenomenon. Why they approach each other, is not yet explained. It has always been assumed that the state of contraction is the active, and the state of relaxation the passive, condition of the muscular fibre, and this is probably still the prevailing belief. But Dr. Radcliffe has advanced the opinion, from a study of the electrical relations of nerve and muscle, that the state of elongation should be regarded as the active condition of this tissue, and that of contraction as the passive condition, or state of rest. By an inversion of the ordinary terms of description all the phenomena can thus be equally well explained, but the doctrine itself is not yet established. It seems natural to suppose, from our knowledge of the polar electrical condition of living muscles, and of the disturbance of its electrical state during contraction, that the dark sarcous elements or disdiaclasts, and the light intervening elements, may be in opposite polar electrical states; and that accordingly molecular attractions and repulsions may, under excitation, occur, as the immediate causes of motion between them; but this is quite conjectural. It has been offered as a mere suggestion, to be hereafter again alluded to, that osmotic changes in the contents of the tubular sarcolemma of the muscular fibre, may possibly occur as essential conditions of its alternate contractions and relaxations (Graham).

The Rigidity of Death, or Rigor Mortis.

Within a certain period after death, the muscles of the body, the muscular substance of the heart, and also the parts composed of the non-striated muscular fibres, undergo, after losing their irritability, a general stiffening, which is called the *rigor mortis*, or *cadaveric rigidity*, or the *rigidity* of *death.* This rigidity in the muscles is so perfect that the joints become fixed, usually in the position in which the body lies at the moment of death; but, in certain cases, the occurrence of the rigor mortis is accompanied by displacements of the limbs, even to the raising up the corpse into a sitting posture. Usually the more powerful muscles give, in dying, and in assuming their rigid condition afterwards, certain definite positions to particular parts of the body; thus, the upper eyelid is drawn slightly upwards, the lower jaw is closed against the upper one (whereas at the moment of death it falls by relaxation of its muscles), the fore-arm is slightly flexed, the fingers are bent, and the thumb turned inwards on the palm; whilst the leg and foot are everted and extended, the flexors of the upper limb and the extensors of the lower limb being stronger than their antagonists. These movements must be distinguished from those which have been observed, soon after death, in cases of cholera and yellow fever, and which are attributed to an unusual persistence of the proper muscular contractility.

The rigor mortis may begin within ten minutes of death, but it usually comes on between seven and eighteen hours, sometimes as late as thirty-six hours. Its usual duration is from twenty-four to thirty-six hours, but it may pass off much more quickly, or last for several, as many as six, days. It disappears at the commencement of putrefaction. The sooner it comes on the shorter its duration, and when it comes on late it continues longer. It appears latest, is most intense, and lasts longest, in persons dying rapidly in a state of health. In sickly, weak, and emaciated bodies, in new-born infants, and in animals exhausted by over-fatigue, it comes on quickly, is weak in its effects, and disappears most rapidly. It is independent of any influence from the nervous centres, for these may be destroyed without preventing its occurrence; and it occurs even in paralytic limbs, when the muscles are not too much impaired in their nutrition. A form of muscular rigidity can be induced in a living animal by stopping the circulation through a limb; and the true rigor mortis itself may be completely removed by injecting defibrinated arterial blood into the arteries of a dead limb. If this be done within a short time after death, the irritability of the muscles is also restored: this effect has been kept up for forty-one hours, the opposite limb in the meantime beginning to putrefy. It would seem that the rigor mortis occurs more slowly, is most marked, and lasts the longest, in direct proportion to the previous amount of nutritive activity and irritability in the muscle. It was stated by Hunter that it did not occur in certain cases of death by lightning; but it has been observed in the body of a dog killed by electrical shock: it has also been said to be absent after death from severe injuries or violent emotions; but in such cases it may have come on very quickly, and as rapidly disappeared. It often begins when the body is still warm. It occurs in drowned persons, and also in the corpse when immersed in water after death. It comes on sooner in cold weather, and in parts exposed to the air. In the human body it first commences about the muscles of the lower jaw and neck, then proceeds to the upper limbs, next to the trunk, and lastly to the lower limbs; it passes off in the same order. The rigidity is completely destroyed by forcible extension; but if the extension be used before it is complete the muscle may again become rigid.

By some the rigor mortis is regarded as the result of a vital contraction, perhaps the last evidence of tonicity; but it commences when the contractility is already enfeebled; and even paralyzed muscles become rigid. Moreover, the state of rigidity itself differs from that of the vital contraction of a muscle, by its uniform and persistent character, and by the diminished cohesion or strength, the smaller extensibility, and the less perfect elasticity or resilient property of the rigid muscular substance, and particularly by the total cessation of all electrical currents in it. By others it has been attributed to a molecular change in the sarcous elements of the fibrillæ, dependent on the stagnation of the blood-current; to a sort of coagulation or setting of the muscle-fibrin of the sarcous substance of the fibrillæ, compared to the coagulation of the blood (see p. 72); to the coagulation of a fibrinous material between the fibrillæ of each fibre (Brücke); or, lastly, to chemical changes giving rise to the production of an acid or alkaline fluid, which stimulates the still contractile muscle. According to this latter view, the rigor mortis is due to a last act of contraction or idio-muscular contraction (Schiff). But its cause is not yet thoroughly understood. When fully established, it is an absolute sign of death.

In the case of the heart, the rigor mortis produces an excessive contraction of that organ. The occurrence of this phenomenon in involuntary muscle, is shown by the rising of water in a glass tube fitted into one end of a piece of the intestine of a recently killed animal, the other end being of course tied, and the cavity quite filled with water. It is also shown by the temporary contraction of dead arteries, which, after a time, again relax.

CILIARY MOTION.

The presence of *cilia* on certain so-called ciliated mucous and serous membranes in man, has been mentioned in the account of the ciliated epithelial tissues (p. 67); and it has been noticed that ciliated epithelium exists on similar membranes of both the warm- and cold-blooded Vertebrata, and in various parts of the bodies of many Mollusca, Molluscoida, Annuloida, Cœlenterata, and Protozoa.

Cilia are found in man and other air-breathing Vertebrata, chiefly in the respiratory passages. They occur in man, in what may be called the middle region of the nasal cavities, in the frontal and other sinuses, in the upper part of the pharynx, in the larynx from below the vocal cords, and in the trachea, bronchi, and bronchiæ, down to the ramifications of the smallest bronchial tubes, but not in the air-cells of the lungs. They are present also in the Eustachian tube and tympanum of the ear, and in the nasal duct and lachrymal sac. They are likewise found on the sides of the ventricles of the brain, and within the central canal of the spinal cord. In the warm-blooded Mammalia, they exist in the same situations as in man. In Birds, they are present likewise in the air-sacs distributed through the trunk of the body. Amongst the cold-blooded Vertebrata, cilia exist, not only in the ordinary situations, but, in Reptiles, in the pericardium, peritoneum, and œsophagus, and also in the uriniferous tubuli, and sometimes in the Malpighian capsules of the kidneys. In the frogs, they are found also on the roof of the mouth; and in the ichthyoid Amphibia, on the gills. In Fishes, the gills are destitute of cilia; but these exist in the cavity of the nose, and in the respiratory chambers of the amphioxus. In the Mollusca and Molluscoida, cilia are found in the alimentary canal and bile-ducts, and on the gills of both the univalve and bivalve kinds; also on the respiratory apparatus, when this consists of simple tentacula (hydrozoa), or is reduced to a respiratory sac or atrium (tunicata). In the Annelida, cilia are commonly found on some part or other of the body; and in the Annuloida, always in the so-called water-vessels and other parts of the scolecida, and in the ambulacral tubes of the echinodermata; also in most aquatic Annelida and Annuloida, on certain parts of the head, probably the seats of an olfactory sense. In the Cœlenterata, they are found very largely developed in the bodies of the ciliograde actinozoa (Beroe, &c.), on the ovarian fringes, and in the interior of certain tubes which ramify through the bodies of the medusoid forms. Lastly, in the Protozoa, they are invariably present upon the surface of all infusoria, and in the interior of certain parts of the ramified tubes of the spongia. They exist, moreover, on the embryos of the amphibia, on the ova or embryos of a large number of the non-vertebrated aquatic animals, and on the gemmules of others. Cilia have not been found in insects, crustacea, myriopoda, or arachnida.

The cilia are microscopic, soft, transparent, colorless, homogeneous, flexible organs, which, from being, in certain places, arranged in even rows, have been compared to the eyelashes, and hence have received their name. They are either thread-like, tapering, blunt, or flattened; they are usually attached to epithelial or epidermoid cells—each cell, in the most characteristic forms, bearing from six to twelve cilia. They vary in length from $\frac{1}{2500}$th to $\frac{1}{4000}$th of an inch in man, and from $\frac{1}{12000}$th to $\frac{1}{1000}$th of an inch in different animals, being largest in the non-vertebrate marine animals, and reaching the greatest size in certain Cœlenterata. On the mucous membranes of the warm-blooded Vertebrata they are less regular in their distribution over the surface; but on the gills of the Mollusca, on the tentacles of the hydrozoa, on the lateral bands or paddles of the Beroe, and on the bodies of certain infusoria, they are arranged in remarkably even lines, and, in each particular case, have a very uniform length.

The ciliary movements are, of course, only observable by aid of a high magnifying power. The motion of individual cilia is difficult of detection, owing to its rapidity. It is sometimes *infundibuliform;* that is to say, the point describes a circle in space, which forms the base of a cone or funnel, the apex of which is at the attachment of the moving cilium. More commonly the movement is *unciform* or hooked, each cilium bending downwards and then straightening itself again, so as to perform a *lashing* movement. In the case of a ciliated surface, this motion appears to affect the cilia in regular succession, so that the result is an *undulatory* movement, like that of running water, moving rapidly along in constantly definite wavy lines. Nothing can exceed in beauty, as a microscopic object, these waving movements of the fringed and feather-like rows of the ciliated gills or branchiæ of one of the Mollusca (mussel, oyster). The average velocity of the ciliary current in the frog's mouth is about $\frac{1}{200}$th of an inch per second, the average rate of the blood in the capillaries of its web being about $\frac{1}{50}$th of an inch per second.

The motion of the cilia has the effect, when the animal is fixed, of producing currents over the ciliated surface in the surrounding fluid medium, in certain definite directions, by which not only the fluid, but any small particles or microscopic living objects which it may contain, are hurried past or over the surface. Indeed, the ciliary movement is best observed and detected, by mixing charcoal or pigment in the fluid in which these organs are examined. In the case of small aquatic animals, and of ciliated ova, embryos, or gemmæ of the same, the effect is to cause a movement in those minute beings themselves, the cilia constituting true locomotive organs. This occurs also in the Beroe, the lateral ciliated bands of which are composed of flat quadrangular plates, built up of large cilia, placed side by side. Most commonly, the direction of the progressive movement is constant, and remains unchanged even on any detached pieces of membrane; but sometimes the motion, as in the case of certain infusoria, is variable in direction, and almost suggests obedience to volition. In the Beroe this is even more obvious. On the gills of Mollusca the direction of the motion is likewise sometimes suddenly reversed.

The ciliary motion continues for one, or sometimes for several days after death, in the amphibia and other cold-blooded Vertebrata, as in the turtle, though for a shorter time in the warm-blooded Vertebrata, often ceasing in birds after the lapse of fifteen to thirty minutes. It endures longer, however, in Mammalia, the time varying from two to forty-eight hours; it lasts longer in warm than in cold weather. The ciliary movement continues for a time on portions of the mucous membrane, detached from the body; and is said to have been observed in the fresh-water mussel even in a state of putrefaction. It is quickened by touching the cilia briskly with a foreign body; also by contact with the serum of the blood. Blood preserves the power of movement, for cilia immersed in it, exhibit motion at the end of three days, whilst water destroys it in three hours. The blood of the Vertebrata arrests the action of the cilia of the Invertebrata. Light does not affect the motion, nor electricity, unless it be strong enough to destroy, or chemically decompose, the tissue. This curious movement is increased in rapidity, and may even be revived by the action of heat: it is diminished by cold; thus, in warm-blooded animals, it ceases at a temperature of 43°, whilst in the frog it continues even at the freezing-point of water. It is retarded by water, and destroyed by various chemical agents, by bile, or even by fresh water, in the case of marine Mollusca; but weak alkaline solutions revive it. The motion is not influenced by narcotics generally, nor yet, it is said, by some poisons which annihilate muscular contractility; but prussic acid may affect it, and it is temporarily suspended, like the muscular action of the frog's heart, by the vapor of chloroform. No nerves have been traced to the cilia, nor do they appear to be governed or influenced through the nerves or nervous centres; their motion continues in the frog for days after destruction of the brain; they exist in animals apparently destitute of nerves; and, lastly, motion may continue in a single cilium detached, with its epithelial cell, from the rest of the body. Furthermore, they have been seen in action in the turtle after the muscles have ceased to exhibit any signs of contractility.

The true explanation of the phenomenon of ciliary motion has yet to be discovered. By some it has been supposed that the cause of the motion is *not intrinsic*, but that it is dependent solely upon certain chemical interchanges between their substance and the surrounding medium. The opposite view, that it is due to the action of an animal substance endowed with a form of vital contractility, seems more probable (Sharpey). No trace of muscular fibres, or fibrillæ, has been found at their base; their motion differs most remarkably from muscular motion, in not being affected by electricity of moderate intensity, or by certain narcotics, and also in lasting much longer after death. But, on the other hand, no particular structure seems to be essential to the possession of contractility, which is manifested equally in the striated and non-striated fibres, in the simple fibre cells, and, as well known, in other single sarcodous cells, and even in masses of protoplasm; it is also exhibited in the heart of the embryo chick, where this is composed solely of nucleated cells, having no fibres developed in it. On this point, too, it has been suggested that the cilia may consist of extremely delicate protrusions of the wall or periplast of the cell on which they rest, like the fingers of a glove, each containing a soft contractile sarcodous material (Kölliker); or, that they may be gymnoplastic offshoots, that is, destitute of a distinct envelope. Again, the longer duration of the movement after death, is only a difference of degree; and this power endures longest in those animals in which muscular contractility lasts longest. Finally, the discrepant action of certain narcotics may be probably explained by future researches. Admitting, however, the probability of the ciliary motion being due to vital contractility, its rapid, rhythmic, concerted, and maintained action yet remains to be explained.

The *use* of the cilia in the respiratory organs of the higher air-breathing animals, may be said chiefly to keep the membranes moist, by distributing over them the secretion from their surfaces and follicles; and secondarily, by the definite direction of their motion, which has been noticed invariably to be upwards towards the larynx, to assist in raising and expelling the superabundant secretion upwards from the air-passages. Their use in the ventricles of the brain, and central cavity of the cord, is not known. On the gills of the young Amphibia (tadpoles), and on the respiratory organs, whether laminated, ramified, or sacculated, of the aquatic Mollusca and Molluscoida, they appear to assist in the respiratory process, by keeping up rapid and continuous currents over the respiratory surface, by which fresh portions of fluid are continually brought into contact with it. In certain cases (Ascidioida, Polyzoa), by creating currents, they also serve to conduct alimentary substances into the opening leading into the stomach, or the mouth, of the animal. As already mentioned, they cause a rotatory movement of the embryos of certain vertebrate and non-vertebrate aquatic animals. Finally, they constitute the proper locomotive organs of the entire animal, in the Infusoria: in some of these (Paramecium) the whole surface is ciliated; sometimes, as in Vorticella, there are a few ciliated fringes only around the mouth; and sometimes, as in the young Vorticellæ, and in other species, there is but a single long tail-like cilium, by the undulatory motion of which, the microscopic being is propelled through the water in the opposite direction.

MOVEMENTS OF ANIMAL SARCODE AND PROTOPLASM.

Movements, undoubtedly due to a vital contractility, take place, as we have seen, in cells not possessed of the complex structure of muscular fibre; such are the movements in the contractile cells of the embryo heart of the Vertebrata, as in the chick or tadpole. In many of the Annelida, and in other animals still lower in the scale, distinct muscular fibres are replaced by an almost homogeneous tissue; the cells of the Hydra, formerly believed to be themselves contractile, are not now so regarded; but are considered as being rather of an elastic nature, having contractile tissue lying between them. Still simpler examples of sarcodous contractile movements occur in the gymnoplastic white corpuscles of the blood, and in the so-called unicellular organisms of a gymnoplastic type, such as the compound amœbiform particles of the Spongida, and the various Rhizopoda, such as the Rotalia, the Actinophrys, and the simple Amœba itself, and lastly, in the still lower Gregarinida. In all these cases, there is noticed a retraction of a soft tissue in certain directions, accompanied by its extension in other directions; this is the essential character of muscular contraction, even in the highest organized fibre. In the more perfect contractile cells, there probably occurs an approximation of true sarcous elements or particles, filling the entire cell; but in the simpler animals above mentioned, as in the Amœba, for example, the movement is confined to the outer firmer layer of amorphous sarcodous substances, the inner portions being semifluid or fluid. All the preceding movements, like muscular contraction, can be excited by electrical, mechanical, or chemical stimuli.

Movements yet more obscure have been seen in mere masses of protoplasm not organized into the distinct cell form, either cystoplastic or gymnoplastic, but merely irregularly aggregated around a nucleus. Such are the budding movements which have been observed in the lymph-corpuscles, and also in the little stellate masses of nucleated protoplasm, known as the connective tissue corpuscles, which, in the frog, especially in the corner of the eye, have been seen to extend themselves in various directions. They are excitable by electrical and mechanical stimuli, and, in the case of the corneal corpuscles, even through the nerves. The curious movements which take place in the pigmentary contents of the colored cells of the frog's skin, also seem only to be explicable on the supposition of the occurrence of like protoplasmic movements.

However simple these sarcodous and protoplasmic motions may be, they are all similar, or at least allied, to those of the sarcous elements of muscular tissue, and the dependence of all on a common vital property seems undoubted, though it may be sometimes actively, and at others obscurely, manifested. Retraction and extension, in different directions, always occur; but these movements are sometimes rapid, and sometimes slow; sometimes they are neuro-motor, and sometimes idio-motor. If the ciliary motion be included in the same category, its extreme rapidity, and its rhythmic and combined character, apparently irrespective of nervous influence, are quite peculiar.

Vegetable Motion.—In the vegetable kingdom two kinds of movements have been observed. Thus, for example, the motions of the leaves of the sensitive plant, of the fly-catching plant, of the stamens of the berberry and other flowers, and of the bifid stigma of the mimosa, may be due to physical changes of an osmotic character, causing a filling or emptying of certain cells; or, as is alleged, in the case of the stamens of the centaurea, the movements may be owing to the action of a true contractile tissue, vegetable sarcode, or protoplasmic substance, contained in a cell (Cohn). The rapid motions of the fertilizing spiral filaments, known as spermatozoids, in the ferns, lycopodiums, and mosses, seem to be analogous, though this is not certain, to the ciliary motions of the singly-ciliated infusoria. The motions of the algaceous volvocinæ, desmidiæ, and others, are almost certainly protoplasmic. Lastly, the remarkable and well-known movements of the contents of certain cells in the vallisneria, chara, and other plants, are of a protoplasmic character: in these cases, globules of chlorophyll, and other minute particles, are seen to move along, in fixed directions, round the interior of the cells, passing, when these are oblong, up one side and down the other, in regular and continued order—the movement really occurring in the fluid contents of the cells, and the solid particles being thus carried along. It has been supposed that the cells were provided with cilia on their internal surface; but of this there is no proof. It would rather seem that the internal surface of the periplast or cell-wall is lined with a layer of contractile protoplasm, in which progressive undulatory movements take place; but how these are caused or regulated is unknown. It is interesting to find in these various vegetable movements, if not an identity with, at least a simulation of, the lowest forms of animal contractility and movements.

MOVEMENTS OF MAN AND ANIMALS.

The various kinds of motion which we have now considered, whether muscular, ciliary, sarcodous, or protoplasmic, are employed, as we shall hereafter see, both in man and animals, not only in the functions of animal life, as in motion and sensation, but also in those of vegetative life, as, for example, in the actions of the digestive apparatus, of the organs of circulation, and those of nutrition, secretion, excretion, respiration, and reproduction. The movements of *animal life*, properly so called, which have now to be considered, have for their immediate purpose either the performance of the various acts of *locomotion*, *prehension*, or *manipulation*, or they may aid in the *exercise* of the organs of *the senses*, or they may be called into play in *expression*, or in the production of *voice* and *speech*. In reference to these intrinsic movements, the animal body may be regarded as a machine, differing from ordinary machines, in being endowed with life, in possessing within itself a source of action or power, viz., vital contractility, and in being composed of certain mechanical parts destined to be moved on each other, except in the lowest forms of animals, in subjection to the internal control of the nervous system, so as to yield *intrinsically* regulated mechanical effects.

Thus, in locomotion, the body, entirely, or by its parts, acts on some external medium, whether solid, fluid, or aerial; and, in consequence of the resistance or reaction of that medium, is moved through space. In prehension, and its higher form, manipulation, certain parts of the body seize, act upon, and utilize materials external to it, according to the innumerable dictates of want, desire, or reasonable will. In aiding the sensory organs, movements are impressed either upon the head, or upon the various sensory organs, or their parts and appendages. In expression, all parts of the body may be set in motion, but in the higher animals, and in man, particularly, the features. In the production of voice, peculiar and rhythmical vibrations of a special part of the frame of air-breathing animals, accompanied by synchronous vibrations in the air, are generated by movements set up in the respiratory apparatus. Finally, speech, which is peculiar to man, and results from the modification of vocal or whispered sounds, is due likewise to muscular actions which are accomplished by the throat, mouth, and lips.

LOCOMOTIVE ORGANS IN MAN.

The parts of the body concerned in locomotion, are usually divided into the passive and active organs of locomotion. The passive organs consist of the bones, joints, ligaments, both fibrous and elastic, and tendons; whilst the active organs are the muscles.

The Bones.

The names of the bones, and their position in the body, are elsewhere mentioned; the microscopic structure of the osseous tissue has also been explained.* The bones support and protect the soft parts of the body, as well as give effect and precision to the actions of the muscles: for these purposes, the bones are hard, somewhat elastic, and resistant. The hardness and strength of bone are sufficiently well known; its elasticity is well exemplified in thin long bones, like the ribs. The hollowness of the long bones, endows them with a greater comparative strength than if the same weight of bony tissue had been employed in the solid form; for it is a well-known fact in physics, that the same weight of material affords more resistance, both to downward and lateral pressure or force, when arranged in a tubular form, than it does when disposed in a solid cylindrical mass of equal length. Independently of its strength, due to the grosser mechanical form or distribution of its substance, the osseous tissue, owing to its microscopical structure, is endowed with a remarkable innate strength and elasticity; for the compact bone, it will be remembered, consists of innumerable interlacing fibres, disposed in the form of numerous concentric laminæ, surrounding the minute branching Haversian canals, and themselves cemented together into one firm mass. More-

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* A few additional details may be here given concerning the structure of bone. The laminæ or lamellæ, as they are called, are either concentrically disposed around the Haversian canals, or they are placed parallel with the general surface of the bone, or they are irregular, and fill up the general substance of the compact tissue. The fibrous structure of these lamellæ is now well established: when decalcified, by soaking in an acid, they are seen to consist of transparent decussating fibres arranged in a compact reticulated manner. The lamellæ are, moreover, frequently perforated by bundles of other fibres, which serve, as it were, to connect them together: these perforating fibres, when decalcified, generally resemble white connective tissue fibres, but some have been compared to elastic fibres. The lacunæ of bone, as shown after maceration in acid, contain each a nucleated cell, which presents an irregular outline like that of the lacuna itself, and is regarded as corresponding with the so-called connective tissue corpuscles (Virchow). Besides the cancelli of the cancellated or spongy tissue of bone, and the short and frequently communicating Haversian canals of the compact tissue, other spaces are occasionally found in the latter, especially in growing bone; they are produced by a process of absorption, and when first formed are irregular in outline, frequently encroaching on neighboring lamellæ; they are named Haversian spaces. The periosteum, which covers the bones everywhere, except at the articular surfaces and on the smooth grooves for tendons, consists of an outer layer composed of white fibrous tissue and bloodvessels, and of an inner layer of elastic fibres. Besides the yellowish marrow, which exists in the long bones, and is composed chiefly of adipose cells, there is in the short bones, and in those of the cranium, a reddish and more transparent medulla, which contains only a few fat-cells, but numerous minute spheroidal nucleated cells, or proper *marrow cells*.

over, the cancelli and larger hollows of the bones, serve to expand their surfaces, and so present broader points for contact with each other at the joints, and broader surfaces for the attachment of muscles. The compact bone is found in the shafts of the long bones, and in other parts where strength is needed; whilst the cancellated structure prevails at the ends of the long bones, and in the parts of the vertebræ that rest over one another. The cavities in bone also secure a greater relative amount of lightness in reference to bulk, for the cancelli and the larger medullary cavities, are filled with a vascular fatty tissue, much lighter than bone; and in certain cases—as, for example, in the frontal, sphenoidal, and maxillary bones—there are spaces occupied by air.

The bones of Fishes, the bodies of which are supported in water, are perfectly solid, whether their skeleton be osseous or cartilaginous. In Reptiles, there are comparatively few medullary cavities or cancelli. These exist in all the Mammalia, but are less marked in the aquatic cetacea. In Birds, many of the bones, which in the Mammalia are occupied by fat, are filled only with warm air.

Other mechanical arrangements in the skeleton also deserve attention; for example, the broad expanded shape of the skull-bones and pelvic bones, for the purpose of protection; the length of some bones, as those of the limbs, where they are destined to act as long levers with unequal arms; the shortness of other bones, as those of the vertebral column and foot, where shock has to be lessened, without any sacrifice of strength, and with the preservation of flexibility and elasticity; the projecting points, or the so-called "*processes*" of many bones, which serve for the attachment of muscles, and, as we shall see, also increase their leverage; the formation of *grooves* for the play of tendons; and, lastly, the presence of holes called *foramina*, for the passage of nerves and vessels. Special adaptations of the forms of different bones to their several purposes, will be exemplified in describing the habitual posture, and the various movements of man and the lower animals.

The Joints.

The *joints*, or *articulations*, permit the various movements of the animal frame; they likewise serve to deaden the internal concussion or shock produced by contact of the body with external objects, and, moreover, they contribute to the strength of the skeleton, especially to that of the back and lower limbs; for it has been shown mechanically that a rod or pillar, of a given height and thickness, has less power of resistance to vertical pressure or crush than a number of shorter rods or pillars built up one above the other to an equal height. Whilst the muscles are the active agents in the movements of the body, and whilst the bones give effect and precision to those movements, it is the form of the surfaces of the bones at the joints which finally determines their exact character and extent.

The joints, in man and the higher animals, are first divided systematically, according to the degree of movement permitted by them, into three different kinds, named the immovable, the mixed, and the movable joints.

The *immovable* joints (synarthroses, from σὺν, *sun*, together, ἄρθρον, *arthron*, joint) include the several kinds of *suture* (sutura, a seam), Fig. 8. The *dentate* or *serrated* sutures occur in the junction of the bones of the upper part and sides of the cranium. In them the indented or serrated edges of the adjacent bones fit into each other, having, however, a thin layer of fibrous membrane passing between them, which is derived from the periosteum and dura mater, and serves not only to unite and nourish them, but to deaden shocks. The suture is called *squamous*, where the adjacent margins of the bones are bevelled off, so that one overlaps the other, as at the junction of the temporal and parietal bones. Sometimes the direction of the bevelling is changed at different parts of the same suture; for, at the upper part of the skull, the frontal bone overlaps the parietals, whilst at the sides the parietals overlap the frontal—an arrangement evidently calculated to stiffen the tie between the two bones. Where the borders of the adjacent bones are elevated, the suture is said to be *limbous* (limbus, a selvage), as in the union of the parietal and occipital bones. In some sutures of the skull, as between the upper jawbones, the palate bones, and others, the opposed margins are smooth or even, and form a *false* suture, named *harmonia* (ἄρειν, to fit). Sometimes a ridge in one bone is received into a groove in another (*schindylesis*, σχινδύλησις), as in the junction of the vomer with the ethmoid. The fitting of the teeth into their sockets, erroneously classed with the joints, is called *gomphosis* (γόμφος, gomphos, a nail).

The *mixed* articulations (*amphiarthroses*, ἀμφὶ, together, or both, αρθρον, a joint) are those in which the opposed surfaces of the bones are joined directly together by some intermediate soft substance, which is fibrous externally, and more or less fibro-cartilaginous towards its central part. The best examples of this joint are found in those between the bodies of the movable vertebræ, from the second downwards, Figs. 9, 10, 12, in the junction of the body of the last vertebra with the sacrum, and in the articulation between the two upper parts of the sternum. The symphysis pubis, or joint between the two hip-bones at the front of the pelvis, and the joints between the ilia and the sacrum behind, also possess the same general characters, but, in some respects, approach the more perfect or movable articulations. The mechanical result obtained in these articulations is great strength, accompanied by slight movement; they serve, in all cases, to deaden shock, and to give elasticity, and, in the case of the movable vertebræ, they allow of limited motion, in all directions, between the numerous individual bones, the total result being considerable flexibility, and possibility of curvature, in the whole column.

The *movable* joints (*diarthroses*, διὰ, through, ἄρθρον, a joint), so called because the severance of the surfaces is complete, these not being joined, but being merely in contact with each other, are the most perfect articulations in the animal economy. In them, the ends of the bones are often expanded and variously shaped, according to the character of the joint, the end of one bone being usually convex and of the other concave, Fig. 3. These ends, or *articular surfaces* of the bones, are moreover covered by a thin layer of closely adherent *cartilage*, which serves to deaden shock, and to facilitate, to the utmost degree, the movements of one bone upon the other. Surrounding the joint closely at all sides, and attached to the opposed bones, near the borders of their cartilaginous articular surfaces, is a membranous sac or closed tube, called the *synovial capsule*, which limits the joint, and secretes a viscid fluid named *synovia*, which serves to lubricate the articular surfaces, and so diminishes friction and prevents the perception of grating, or noise, to the individual. This ropy fluid escapes when a joint is opened, and is vulgarly called *joint-oil*, though it is not of an oily or greasy nature, but is an albuminous liquid, which has an alkaline reaction and a slightly saline taste; it resembles the white of egg; hence its name (from σὺν, *sun*, like, ὠὸν, an egg). Outside the synovial capsule, and more or less blended with it, are the proper connecting tissues between the bones, or the special *ties* of the joint, called the *ligaments* (from ligare, to tie). These ligaments are composed of white fibrous connective tissue. In certain parts, the fibrous bands of which they consist, are spread out, and merely strengthen slightly the loose synovial capsule; at other parts, they are collected into dense bands of various shapes, tying the bones very firmly together. Besides permitting motion between the bones, the ligaments are generally so inserted around each articulation, as to restrain the movements in certain directions, or at some determinate point. Sometimes the muscles, or else the tendons of muscles, exercise what might be called a ligament-like protection around a joint; as, for example, the muscles around the shoulder, and the tendons around the ankle-joint. The articular surfaces of the movable joints are also held together by the atmospheric pressure which acts on the whole body. This is best exemplified, experimentally, in the ball and socket joints, and especially in the hip-joint, as will be presently mentioned.

The movable joints, or diarthroses, are classed in *three* divisions, according to the shape of their articular surfaces, and to the character of the movements performed at them. In the simplest form, the surfaces are more or less plane, and the movements gliding; these are the *planiform* joints, sometimes called *arthrodia*. They are met with chiefly, in the tarsal and metatarsal articulations of the foot, and in the carpal and metacarpal articulations of the hand; also in the articulations of the collar-bone with the scapula and with the sternum, in the articulations of the lower jawbone, in the junction of the upper end of the fibula with the tibia, in the joints between the occiput and atlas, and between the articular processes of the several cervical and dorsal vertebræ, in the junctions of the tubercles of the ribs with the vertebræ, and in those of the costal cartilages with the sternum. The ligaments of such joints are usually short and strong, especially in the foot and hand, and, together with the neighboring processes of bone, serve to check the movements of the bones. These joints allow of limited motion in many directions, deaden shock, and impart elasticity and slight flexibility, without impairing the strength of the part in which they are found.

The second kind of movable joints have *pulley-like* surfaces, and execute *hinge-like* movements; hence they are called *trochlear* (from trochlea, a pulley), or *ginglyform* (γίγγλυμος, a hinge). In these joints, the end of one bone is modelled so as to present a median groove with two lateral projections; whilst the end of the other bone has a median projection and two lateral concavities; or the surfaces are otherwise adapted by opposite curves, so as to admit of free motion in one plane only, though, of course, in two directions, viz., backwards and forwards. The best example of this kind of articulation, amongst the larger joints, are to be found in the elbow, the ankle, the wrist, and the knee (Fig. 3); the knee being the least perfect, because, when flexed, it permits of slight rotation. In the smaller joints, the articulations of the phalanges of the fingers and toes with one another, are also examples of hinge-joints. In these joints the ligaments, on one aspect, which may be called the aspect of extension, from which the joint can be most strongly bent, are more or less thin and loose; whilst at the sides, and on the aspect of flexion, they are, as a rule, very strong: this twofold arrangement gives the necessary strength to a hinge-joint, without impeding, or preventing, its almost complete flexion. In the knee, especially, the lateral ligaments and the posterior ones, which project into the back of the joint, and have a *crucial* form (Figs. 3, 8), serve to check the extension of the leg upon the thigh, when the one is in a line with the other; and, in the act of standing, when the weight of the body is thrown upon the fully extended knee, these ligaments save the expenditure of much muscular force. In the case of the fingers and toes, the flexor and extensor tendons act as additional ligaments to the joints.

The third kind of movable articulations have *ball and socket* surfaces, and power of movement in all directions; they are named *enarthrodia*. In these joints, the one bone presents a cuplike cavity, or *socket*, either shallow or deep, lined, of course, with cartilage; whilst the other bone presents a rounded extremity, forming, more or less, part of a spheroid, and also covered with its cartilage. When the receiving cavity is shallow, it is called a *glenoid*, when deep, a *cotyloid* cavity. Examples of the ball and socket joint are met with in the hip, which is the most perfect of these joints in the body; in the shoulder; in the head of the astragalus, amongst the tarsal bones, where this moves in the cup-shaped cavity of the scaphoid bone; in the head of the os magnum, amongst the carpal bones, where it articulates with the scaphoid and semilunar bones; and, lastly, in the several joints at the *bases* of the fingers and toes, where these articulate with the rounded heads of the metacarpal and metatarsal bones. The synovial capsule of the ball and socket joints, is generally loose; but it is fortified by strong ligaments in certain positions, where the motion requires to be restrained. In the larger joints of the shoulder and hip, the cavity of the socket is deepened by a fibrous rim or border attached all round its margin. In the shoulder, the tendon of the biceps muscle passes through the joint, and, undoubtedly, exercises a ligamentous control over it, and affords it support; whilst, in the hip, an internal ligament, named *ligamentum teres*, passes from one bone to the other, that is, from the pelvis to the head of the femur, within the joint, offering an exceptional structure in the anatomy of joints, and serving as an important check ligament, which is brought into use in the act of standing. The hip-joint is very secure, and yet the movements which it permits in the thigh, are very free; for the thigh may be moved so as to make with the trunk the following angles: forwards, 130°; backwards, 40° to 60°; outwards, 90°; and inwards, somewhat less. If the hip-joint be exposed, and the synovial capsule be opened, the head of the bone remains in the socket, or acetabulum. This is due, neither to the ligamentum teres, nor to the fibrous rim which deepens the socket, but to atmospheric pressure; for, on making a small aperture from the pelvic cavity through into the socket, air enters, and the head of the bone falls out (Weber). The same thing happens if the opened joint be suspended under the receiver of an air-pump, and the air be then exhausted.

There are certain forms of movable joint, which require special description. The articulation between the upper ends of the *radius* and *ulna*, sometimes named *diarthrosis rotatorius*, or *lateral ginglymus*, may be called a *ring*, or *collar*-joint; for the side of the head of the radius, convex in shape, is received into a little cuplike cavity on the side of the ulna, from which a strong ligamentous ring or collar, 4, Fig. 54, passes completely round the head of the radius, tying it to the ulna, and permitting the former bone to rotate round its long axis, whilst resting upon the latter. The joint between the *atlas* and the *axis*, is also somewhat similar in principle, but differs in its details: thus the dentate process of the second vertebra, or axis, is received into the anterior part of the ring of the atlas, and is held in position by transverse and vertical bands of ligaments crossing behind it, named the *crucial* ligaments; but the second vertebra is also connected to the skull, for two check ligaments pass from the tip of the tooth-like process, obliquely up to the occiput, and prevent the head from rotating sideways beyond a certain point. The articulation between the *first vertebra* and the *occiput*, is effected in reality by two small gliding joints, the occipital condyles, which project downwards on each side of the foramen magnum, being received into two concave surfaces formed on the atlas. As there are here two separate joints, one on each side of the median plane, the movement is limited to a *rocking* motion, forwards and backwards. The *nodding* motion of the head is accomplished between the cranium and first vertebra of the neck; whilst the *rotation* of the head from side to side, carries the atlas with it upon the axis; the upper part of the spine may participate in both these movements.

In certain other joints, plates of fibro-cartilaginous tissue are interposed between the articular surfaces of the bones. Thus, in each of the two articulations of the *lower jaw*, by means of its two condyles with the very shallow glenoid fossæ of the two temporal bones, there is such an *inter-articular cartilage;* this is either very thin, or perforated, in its centre, but thick at its margins; it is perfectly movable, though attached to the synovial membrane all round, and it follows the movements of the jaw, so as to guard it from dislocation. The double character of the articulation of the lower jaw with the temporal bones at the base of the cranium, also necessitates a hinge-like action of this upon the skull; at the same time, other slighter, lateral, and backward and forward, movements are permitted. Again, between the inner end of the *clavicle* and the *sternum*, there is also an inter-articular fibro-cartilage, which passes obliquely from the upper border of the collar-bone to the cartilage of the first rib, close to the lower border of the socket in the sternum. This direction is the one best fitted to resist thrusts or shocks coming from the shoulder, which must constantly take place in the action of the upper limb. Passing sideways from the *lower end of the radius* to the lower end of the *ulna*, is another fibro-cartilage, 8, Fig. 54, which ties those bones together, whilst it permits the radius, which is marked on its inner side by a slight concavity, to roll or rotate on a corresponding convexity upon the ulna. Lastly, in the *knee-joint*, are two remarkable fibro-cartilages, having a more or less crescentic form, and hence called the *semilunar cartilages*. They rest on the upper end of the tibia, and present their convex thick borders towards the outer and inner sides of the joint respectively, where they are attached to the synovial membrane and ligaments, whilst their thin concave borders are turned towards each other, *i. e.*, towards the centre of the joint; they serve to deepen the two shallow sockets on the head of the tibia, into which the condyles of the femur are received.

Elastic ligaments.—Between the arches of all the movable vertebræ, with the exception of the atlas and axis, also between the arch of the last lumbar vertebra and the corresponding part of the sacrum, very peculiar ligaments are found, differing in nature from the white fibrous ligaments which, as their office requires, are essentially non-extensible. These peculiar ligaments, the *ligamenta subflava*, are composed of yellow elastic tissue, and are highly extensible and elastic; they not only serve to connect the bones, but exercise a special mechanical office, yielding, for example, to permit of the slight separation of the vertebral arches from each other in the forward bending of the spine, and assisting mechanically, by their elastic recoil, in the re-erection of the body, and in its due maintenance in an upright posture, thus counteracting the effect of the muscles which would flex the spine. The yellow elastic tissue, indeed, is used here, as elsewhere, in the economy, to sustain weight or any force, or to overcome constant resistance, without the expenditure of muscular power.

The *tendons*, *fasciæ*, and *sheaths* of the muscles.—The *tendons of the muscles*, as we shall immediately see, serve to convey the muscular force from, and to, definite parts of the skeleton, and should therefore be regarded amongst the passive organs of locomotion; they have merely mechanical functions, whether they be considered as adjuncts to the muscles, or as contributing to the support of the joints over which they pass. The *fasciæ*, too, are strengthened in certain parts, and are so arranged as to inclose, or bind down, subjacent muscles, generally or individually, in special *sheaths*, and so prevent them diverging from their required lines of action; and it is certain that they aid in muscular efforts, by holding and supporting the muscles. They are therefore, likewise, passive organs of locomotion. Even the loose cellular tissue, which immediately invests the muscles, and facilitates their constant changes of form and position, may be similarly regarded.

The Muscles.

The microscopic structure and the vital properties of the muscular tissue, both in man and animals, have already been fully described (pp. 48, 130); and also the general mode of construction of the muscles (pp. 21, 49). The number of separate muscles on the two sides of the body is, according to the ordinary mode of division, upwards of 500. The muscles vary in size, some weighing only grains, and others pounds, as, for example, certain minute muscles in the tympanum of the ear, and the vasti muscles of the thigh; in length, they range from two lines to two feet. The form of muscles also varies considerably, according to their position and use; and so likewise does the arrangement of their fasciculi. Usually these latter are disposed longitudinally, but sometimes they form circular bands. On the trunk of the body the muscles are generally broad and flat; in the limbs, on the other hand, they are narrow and elongated—the deep ones, however, being here also broad. Some of the broad muscles are square; others triangular, or lozenge-shaped; and some are indented, or serrated, at their edges; the long muscles are flat and ribbon-shaped, round and fusiform, or, when their fibres are attached obliquely to the sides of a tendon, either penniform or semi-penniform. For the most part, the muscles are attached by both their extremities to the bones, either directly, or indirectly by means of the white, flexible, but inelastic cords, called tendons; but sometimes they are attached to bone by one extremity only, the other being fixed to the skin, or some other soft part, as, *e. g.*, certain of the muscles of the face, and those of the eyeball. Sometimes a muscle has no connection with bone whatever, as the little muscle in the palm (palmaris brevis), and the orbicularis muscle which surrounds the mouth. In the case of a muscle attached to bone by one end only, that attachment is called its origin, the other being termed its insertion; in the case of muscles attached at both ends to the bones, that attachment which is nearer to the centre of the body, and which is also usually the more fixed point, is called the *origin*, whilst the more distant, usually the more movable, attachment, is named the *insertion*. Muscles may have two points of origin, or heads (biceps of the arm), or three (triceps), or many (great serratus); and, again, some muscles have more than one point of insertion (flexors of the fingers and toes). Muscles sometimes pass from bone to bone, over only one joint (deltoid), but often they pass over two (biceps), or more joints (flexors of fingers and toes, and long muscles of trunk). Tendons of origin of muscles, that is, tendons by which they arise, are usually broad; whilst tendons of insertion are generally long and roundish. The tendons of origin enable a large number of muscular fibres to act from a given point of the skeleton; whilst the tendons of insertion transmit the muscular force to some other, and equally precise, point of bone; hence, they are inextensible, and inelastic. By means of the tendons, also, the muscular force is more conveniently reflected over the joints, or other parts of the skeleton, than could be effected by the tender sensitive muscle itself; in this case, the tendons often run in grooves in the bones, lined by cartilage. It is, furthermore, obvious that by the use of tendons, as extensions of the muscles, economy of muscular tissue, and lightness and elegance of form around the joints, are secured. In certain broad muscles, however (gluteus, great serratus), the muscular fibres arise, at least in part, directly from the periosteal covering of the bones.

In undergoing contraction, muscles which are connected only with soft parts, simply constrict or tighten those parts. Muscles which are attached by one end to bone, and by the other to soft tissues, exercise a direct traction upon those parts, moving them in accordance with their mechanical arrangements. The tendon of the superior oblique muscle of the eyeball passes through a loop, which resembles a pulley, the tendon being reflected in a new direction beyond it, so that the movement impressed upon the eyeball is at an angle with the line of direction of the contracting muscle. When muscles are attached by both ends to bones, their action is after the manner of the so-called levers of mechanics; and either the efficient action of the muscle may be exerted in the line of direction of its fibres and tendons; or, by the reflection of its tendon of insertion over some bony point, its force may be exerted at a certain angle from its own direction. It is important also to notice that the tendons of insertion, and sometimes also the tendons of origin, are attached to special eminences of the bones, called *processes;* in which case, a muscle acts at an advantage, because its force ultimately operates, from or on to the bone, in a line more or less perpendicular to the osseous surface, instead of in a line nearly parallel with it, as would happen if the surface of the bone were flat, instead of being so elevated. Muscles which pass over the back of a joint, are usually called extensors, because they serve to stretch, or extend, the part beyond the joint; whilst those lying in front of the joint are, for the opposite reason, called its flexors. Other sets of muscles are known as pronators, supinators, rotators, or levators and depressors, according to their respective uses. The names of many muscles are derived from the number of their divisions, their shape, position, points of origin and insertion, or from the direction of their fibres. In certain cases, a single muscle will contract to perform a given action, as in the raising of the upper eyelid: sometimes two or three are called into action together, as in extending the fore-arm at the elbow-joint (triceps, anconeus), or in flexing the same (biceps, brachialis anticus, supinator longus); but on the other hand, much more commonly, many muscles concur in the production of a single act; and, indeed, indirectly, nearly every muscle of the body is employed in most movements, either in fixing some parts of the skeleton, or in moving other parts.

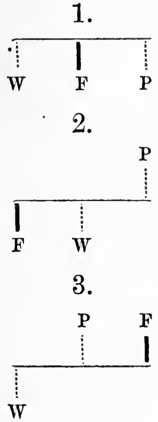
The *rapidity* of action of any given muscle, depends directly on the length of its fibres, for the period of contraction is practically the same in long or short muscles, the fibres of one of which may be twelve, and of the other only three inches in length; and, therefore, the amount of contraction in them, in a given time, will be as four to one. On the other hand, the *power* of contraction, or the force of a muscle, is in proportion to the number of its fibres; and hence, in all the most powerful muscles, the fibres are very short, but so arranged on the tendons as to be very numerous. Notwithstanding the perfection of these, and other more mechanical, arrangements in the body, it happens always, in its more important movements, that there is a disproportionate expenditure of actual muscular power, in comparison with the useful work accomplished. This is well illustrated in the effort required to maintain the position of standing on one leg.

Mechanics of the Body.

Under this head, we may consider, generally, the distribution of weight in the body, or its *centre of gravity*, its *basis of support*, and the nature of the *levers* employed in the movements of its several parts.

The entire body, being comparable to any other solid mass having certain cubical contents, must have its *centre of gravity* placed at the point of intersection of its three planes—the median-vertical, the antero-posterior vertical, and the horizontal plane, determined by reference to its weight. Of these planes, the median-vertical, of course, corresponds with the median plane of the body, and may be found approximately by a plummet line, when the body is in an erect position; the horizontal plane is found by balancing a man, lying with the arms by his sides, upon a plank, which is supported on a transverse knife-edge; and lastly, the anterior-posterior plane is determined by a corresponding method. The point of intersection of these planes, or the normal centre of gravity, when the arms are hanging down by the sides, is generally said to lie in the cavity of the pelvis, a little in front of, and above, the lumbo-sacral articulation; but, by Weber, it is said to be in the promontory of the sacrum, and, by Meyer, in the vertebral canal, opposite the second sacral vertebra. The slightest displacement of the head, or inclination of the body, a swinging or lateral elevation of either arm, or even stooping, changes, temporarily, the position of what may be called the symmetrical centre of gravity, which of course shifts its situation in the direction of any partial displacement of the movable portions of the frame. The centre of gravity of the head and trunk together, in the sitting position, is midway between the point of the sternum and the vertebral column; and the centre of gravity of the head alone, is opposite a point, above, and anterior to, the opening of the external ear. Elaborate observations have also been made as to the position of the centres of gravity of the upper and lower limbs, and of each separate section of the same.

The *basis of support* of the body, necessarily varies in the recumbent, standing, and sitting posture. As in the case of other solid masses, when the centre of gravity is so placed, that a line, let fall perpendicularly from it, strikes within that base, the equilibrium of the body is easily maintained; but when such a line falls beyond the base of support, the equilibrium of the body becomes unstable, and the body has a tendency to fall down.



The *levers* employed in the body, are the three ordinary levers known in mechanics. A lever consists of a *rigid rod*, movable in one plane, around a point in the rod, called the *fulcrum*. In actual practice, this fulcrum is seated opposite the point of support; a *weight* or resistance also exists, which has to be moved or overcome; and lastly, there is a force or *power* to move the weight, or overcome the resistance. The three kinds of levers are distinguished from each other by the relative positions in them of the fulcrum, the weight, and the power. In the *first* kind, 1, the fulcrum F is placed between the weight W and the power P: it is employed in the balance, in working a pump-handle, and in raising the coals in a grate with a poker. The *second*, 2, has the weight W placed between the fulcrum F and the power P: it is used in raising a weight by putting a crowbar underneath it, and also in wheeling a wheelbarrow. In the *third* kind, 3, the power P is placed between the fulcrum F and the weight W: it is used in the foot-piece of a lathe, and in drawing a ladder from the wall, by pulling on one of the steps near the bottom, whilst the foot is placed to prevent its slipping out. Fire-tongs and sugar-tongs are double levers of the third kind. On comparing the three kinds of levers, it will be seen that the terms on each side are twice repeated; but that the middle terms consist, respectively, of the three important elements of the lever, arranged in methodical order, viz., in the first kind, the fulcrum F, or point of support, is in the middle space; in the second kind, the weight W; and in the third kind, the moving power P.

Fig. 48.

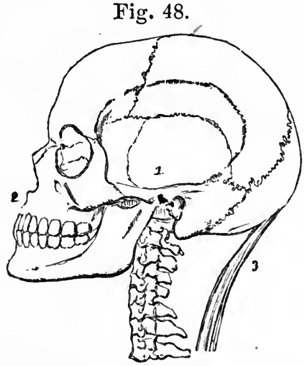


Fig. 48. Example, from the body, of a lever of the first order, shown in the balance of the head on the top of the vertebral column. 1, position of the fulcrum, at the articulation of the cranium with the first cervical vertebra; 2, the weight, or excess of weight, in the fore part of the head and face; 3, the power, in the muscles at the back of the neck.

In the body, the fulcra are sometimes in the joints, and sometimes at the extremity of a limb, in contact with the ground, or with some external point of resistance. The bones constitute the rigid rods, and, with the parts attached to them, the weight to be moved. The muscles are the source of the power. The first kind of lever is illustrated in the adjustment and movement of the skull upon the first vertebra of the neck, Fig. 48; the fulcrum, 1, here being in the transverse plane of the two articular surfaces of the atlas; the weight, 2, is the excess in gravity of the parts of the head and face in front of the joint, over the weight of the parts behind it; whilst the power, 3, resides in the muscles at the back of the neck, extending from the spine to the cranium. The movements of all the vertebræ on one another, from above downwards; the movements of the lowest lumbar vertebra on the sacrum; of the pelvis on the thigh bones; of the thigh on the leg; and of the leg on the ankle, are also examples of the first kind of leverage; so also is the extension of most of the joints in the limbs, as the elbow, knee, ankle-joint, and knuckles of the fingers and toes. The second kind of lever is illustrated in the foot, whilst it rests upon the ground with the heel raised, Fig. 49; here the

Fig. 49.

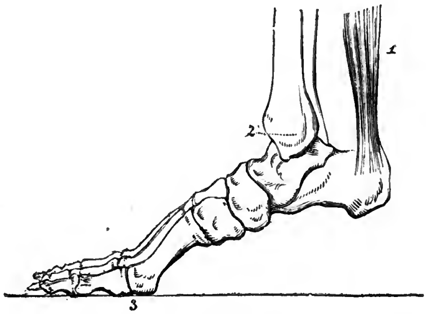


Fig. 49. Example of a lever of the second order, shown in the lifting of the body, by raising the heel from the ground. 1, the power, in the muscles of the calf; 2, the weight of the body transmitted through the leg bones to the foot; 3, the fulcrum, at the ball of the great toe, where it rests on the ground.

fulcrum, 3, is the ground or floor beneath the ball of the great toe; the weight, 2, is that of the body transmitted through the leg; whilst the power, 1, resides in the muscles of the calf, which pull by the great tendo Achillis on the heel bone. The depression of the lower jaw, in opening the mouth wide, affords another illustration of this kind of lever. The third kind of lever, which is much more frequently used in animal mechanics, is employed in raising the lower jaw, in moving the ribs, in raising the collar bone and shoulder; and especially in the flexion of all the joints of the limbs. The most familiar example is in the elbow joint, Fig. 50; here the fulcrum, 1, is in the joint; the weight, 3, is the fore-arm and hand, without, or with, some additional object in the latter; whilst the power is in the biceps, 2, and brachialis muscles, which are inserted, respectively, into the radius and ulna, in front of the centre of the motion in the joint.

The relative advantages or disadvantages of the several levers, mechanically considered, depend upon the proportionate distances, in each case, between the fulcrum and the weight on the one hand, and the fulcrum and the power on the other. The distance from the fulcrum to the weight, gives the length of the *weight-arm* of the lever; whilst the distance from the fulcrum to the power, gives the length of

Fig. 50.

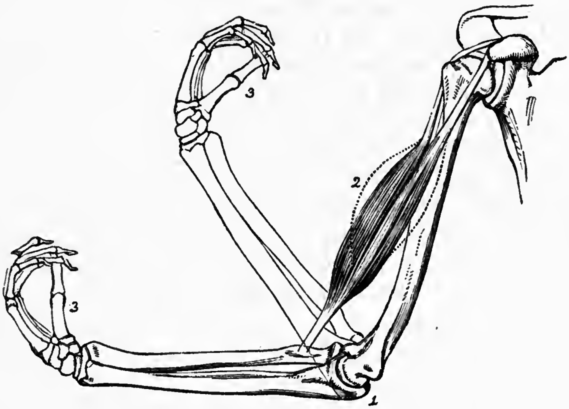


Fig. 50. Example of a lever of the third order, exhibited, in raising the hand, by bending the elbow; 1, the fulcrum, situated at the centre of motion in the elbow joint; 2, the power, partly resident in the biceps muscle, which is fixed to the radius: the two heads of this muscle are shown, and the dotted lines indicate the shape of the contracted muscle (the brachialis muscle is omitted); 3, 3, the weight resident in the fore-arm and hand, which are shown in two positions, that is, before and after, being raised by the contraction of the muscles.

the *power-arm*. When the weight-arm and the power-arm are equal in length, the power to balance or counteract the weight must be equal to the weight, and the slightest excess will overcome its resistance or move it. When, on the contrary, the power-arm is longer than the weight-arm, then the power needed to balance and to overcome the weight is proportionately so much less. Lastly, when the power-arm is shorter than the weight-arm, the power necessary to balance or move the weight becomes proportionately so much greater. Conversely, when an advantage is gained by a particular lever in regard to *power*, there is a proportionate loss in reference to the *velocity* of movement in the weight; for, though when the power-arm and weight-arm are equal in length, the velocities of the power and weight are equal; yet when the power-arm is longer than the weight-arm, and there is a gain in regard to the useful force exerted by the power, there is a loss in the velocity of the weight, which moves through a smaller space than the power; and again, when the power-arm is shorter than the weight-arm, in which case there is a loss of power, there is a corresponding gain in the relative velocity of the weight, as compared with that of the power.

In the first kind of lever the lengths of the weight-arm and of the power-arm may either be equal, or may vary in either direction; but in this respect, there is practically, in the human body, a tolerable equality between them. In the second kind of lever, however, there is, necessarily, always an advantage of length on the side of the power, subject to an equivalent loss in velocity; and it is remarkable that almost the only instance in which this lever is employed in the body, is where great force is needed, viz., in lifting the body by raising the heel from the ground; for then the whole weight of the body has to be lifted on one limb, as in the alternate steps in the act of walking. In the third kind of lever the power necessarily acts always at a disadvantage, accompanied, however, by an invariable gain in velocity on the part of the weight; and hence a moderate amount of contraction in the biceps of the arm, for example, see Fig. 50, moves the hand at the end of the fore-arm, through a relatively large extent of space. The gain in velocity, numerically estimated, is exactly proportionate to the length of the weight-arm of the lever, as compared with that of the power-arm; in other words, to the distance between the fulcrum and the weight, as compared with the distance between the fulcrum and the power. If, for example, the latter distance be one inch, and the former ten, then a contraction of the muscle to the extent of one inch will move the former through ten inches of space.

A force acting perpendicularly on the arm of a lever, operates the most advantageously; hence, in the case of muscles acting obliquely, a loss of power necessarily occurs, so that they require to be proportionally increased in the number of their fibres, which gives them greater power. Speaking generally, the flexors act more favorably than the extensors, and most advantageously, as they approach the utmost limits of their contraction. In the extensors, moreover, the power at all times acts obliquely; hence they are larger, or more bulky, than the flexors, in the ratio of eleven to five.

In comparing the mechanism of the various movements of the body, with that of ordinary levers, it is important to note the fact, generally overlooked, that, in the living body, the power exerted is intrinsic, instead of being extrinsic, or applied from without, as in the common levers. The animal mechanism presents, indeed, examples of the exercise of what are called, in mechanics, *intrinsic forces*. The application of such a force to a lever, so as to produce motion in that lever, necessitates a hinge-like action at the fulcrum, and sometimes even at the seat of the weight, otherwise no motion could take place. Moreover, the production of this internal motion involves a loss of actual lifting force, acting on the weight; lastly, there is not, as in the use of extrinsic forces, any part of the weight supported from without. For these reasons, a much larger amount of muscular power has to be provided for, in the intrinsic exercise of force within the body, than if the force employed were extrinsic, or were applied from without.

External Resisting Media.—Forms of Progression.

The locomotive acts of man and animals are influenced by the media upon, or in, which they move, and their whole organization is modified and adapted accordingly. Thus, we observe progression upon the surfaces of solid bodies, performed either in air or in water;

progression upon water in air; progression in water; and lastly, progression in the air alone; but locomotion on solids, locomotion on or in water, and locomotion in the air, constitute the chief forms of progression.

In ordinary locomotion upon *solids*, the weight of a man or animal is supported on those bodies; and in moving upon them, the centre of gravity of the living animal is invariably raised from the base of support, as it is moved onwards, and then descends again, so as to describe a curved line. The muscular force necessary to move the animal, operating through the lever-like bones, impinges on the solid basis of support; and, as this is assumed, in the simplest case, to be practically immovable, the force exerted acts upon the animal itself, and so lifts it, and moves it onwards in space. Supposing the base of support to be more or less yielding, as in the case of soft ground, or of the flexible twig of a tree, then a certain amount of the force exerted by the animal, is lost in disturbing the basis of support, a part only being left to accomplish the movement of the animal.

In progression upon a solid body, performed *under water*, the same principles are involved; but the muscular effort required to lift the centre of gravity of the animal, is much less than in locomotion upon a solid support in the air; because the weight of the animal is partially sustained by the hydrostatic pressure of the water; and only that part of its weight, which is in excess of the weight of an equal bulk of water, has to be lifted up from the base of support. At the same time, the surrounding medium being heavier than air, a greater resistance is offered to any onward movement; a condition which more than neutralizes the advantage just named, and which renders it more difficult to move rapidly at the bottom of a river, than to run in the air.

In progression *upon a fluid*, as in the case of a swimming bird, the conditions of support are those of partially submerged or floating bodies, and are quite peculiar. The weight of the animal is entirely supported by the displacement of a quantity of water of equal weight; and no effort on the part of the animal is necessary to sustain it above its base of support. All its power is, therefore, free to be exerted in progressive movement, which, however, is performed at a disadvantage; first, because of the resistance offered by the displaced water to the submerged part of the body; and, secondly, and this is more important, on account of the imperfect stability of the medium against which the muscular force acts, for a very large part of that force operates merely in putting that medium into partial motion, whilst only a small portion acts, or rather reacts, from the imperfectly resisting medium, to set the body of the animal in motion through it. Hence, the movement of an animal upon water, can never be so rapid as the movements of certain animals over the land.

In progression *in water*, the weight of the animal, as in the case of fish, is mainly supported by the equal hydrostatic pressure of that medium; and only that smaller portion of weight, which is in excess of the weight of its own bulk of water, operates so as to make it descend in that fluid. Accordingly, a very small proportion of the muscular power exerted is absorbed in the effort to sustain, or lift, the centre of gravity; whilst by far the larger proportion of that force can be employed in the progressive movement. The mode in which that force is exerted upon the water behind the animal, so as to overcome the resistance of that fluid in front of it, will be explained in speaking of the swimming of fish.

In flight, or progression *through the air*, the resistance of the medium in which the animal moves, is reduced to its lowest possible degree, air being proportionally so light and elastic. But the difficulty of moving in it is thereby greatly increased; for almost the entire weight of the animal's body has to be raised from the earth, against its gravity, only so much of that weight being supported by the air, as is equal to the weight of an equal bulk of air, *i. e.* an almost inappreciable quantity. In this kind of movement, therefore, the principal object to be attained by a bird, for example, is to lift and sustain its weight in the air; the progressive movement forward, being the result of the co-operation of the gravity of the animal acting downwards, and the lifting power acting upwards and forwards. The feeble resistance of the air to the movement of the bird, is more than counterbalanced by its imperfect character as a medium for support, and for the development of that reaction which is necessary for the ascensive and progressive movements of an animal in it. The manner in which, by special contrivances, this reactionary force is obtained, will be described under the head of flight in birds.

On comparing the three chief modes of progression, it appears that less force is needed in the fish moving in water, than in the quadruped moving over land, and less in the latter than in the bird moving through the air. Nevertheless, it is a good illustration of the perfection of the mechanical and physiological adaptations of animals, to find that the velocity attainable by certain birds is greater than that attained by any quadruped or fish; the rate of movement of the hawk is said to be 150 miles per hour; that of the swiftest race-horse, Eclipse, 56 miles per hour; and that of the salmon 20 or 25 miles per hour. The quick walking pace of man is about 5 miles, and his running pace about 10 miles per hour.

Locomotion of Man on Solids.

The only position of the human body, in which the muscles are entirely passive and relaxed, is the *recumbent* posture; the respiratory muscles in that case being alone necessarily in action. In *raising the body* from such a position, the lower limbs are usually drawn up; the heels are planted on the supporting surface, to offer a steady basis of support; one or both upper limbs are put forward, to assist in balancing the trunk upon the tuberosities of the ischial bones, an act which is partly performed by the muscles which pass from the thigh to the pelvis and vertebral column; the vertebral column itself is maintained in position by the powerful muscles of the abdomen, acting from the pelvis upwards upon the ribs; and lastly, the head is supported forwards upon the trunk, chiefly by the action of the sterno-mastoid muscles.

In the *sitting* posture, as upon a chair (and also in that upon the ground), the weight of the trunk is supported upon the tuberosities of the ischia, and not upon the lower end of the vertebral column or coccyx: but, in this attitude, the weight is partly balanced, and supported by the thighs resting upon the chair, whilst the feet, touching the ground, serve to steady the thighs.

In *rising* from such a posture to the *erect* attitude, the relative positions of the base of support, and of the centre of gravity, are instinctively adjusted, so as to economize, as much, as possible, the muscular force. The body has, in fact, now to be supported upon the comparatively narrow base of the two feet; whilst its centre of gravity has to be elevated in the air, by the additional length of the thigh bones. Accordingly, when we rise from a chair, we draw backwards one or both feet close to, or even beneath the chair, and then incline the body forwards, so as to bring its weight as much as possible over the future base of support; when, by the contraction of the muscles of the calf, acting from below, the leg bones are brought into a vertical position over the ankle-joints; by the muscles in front of the thighs, acting from the patellæ, the thighs are drawn into a vertical position upon the legs; by the muscles at the back of the thighs, and by the great glutei and other muscles at the back of the pelvis, this latter part of the skeleton, together with the trunk generally, is rolled backwards, and so erected upon the heads of the thigh bones; by the muscles of the back, the vertebral column is drawn into the upright posture; and lastly, by the muscles at the back of the neck, the head is supported upon the vertebral column, with the face directed forwards. In this action, then, of rising from the sitting posture, the several angles between the foot and leg, the leg and thigh, and the thigh and trunk, are opened out; and the body assumes its extreme length.

The erect posture, the characteristic attitude of man, is therefore by no means a passive, but, essentially, an active attitude; and, though not locomotive, in reference to the base of support, is really a locomotive act in reference to vertical space above the base of support. It requires, indeed, the active and energetic employment of a multitude of muscles, not only to assume it, but also to maintain it, as is well illustrated by the facts, that children are unable to stand until after many trials, and that adults stumble, or fall, when the nervous power, which commands or controls the muscles, is lessened or suspended, as in drunkenness, apoplectic seizures, fainting, or sudden suffocation; in which cases, the body, with its system of internal movable levers, the bones, doubles at its various angles, collapses, and falls to the ground. Nevertheless, we find on examination, that these bones are admirably constructed, and shaped for supporting their own weight, and the weight of the parts attached to them, in the erect position, every portion of the skeleton, affording directly, or indirectly, evidences of design in its adaptation to that posture (see Figs. 1, 2).

Thus the human *foot*, from its great breadth, the flatness of the toes, and the parallel arrangement of the metatarsal bones, Figs. 51, 52, is admirably adapted for the support of weight. The foot, moreover, forms a strong double arch. The chief arch, Fig. 52, from before backwards, passes from the broad os calcis, or heel bone, 2, through the astragalus, 1, and other bones of the tarsus, 4, 6, 7, and metatarsus, 8, as far forward as the balls of the toes, the chief support in front, however, being in the ball of the great toe *. The extension of the phalanges of the toes, 9, 10, 11, forwards, from this arch, serves to increase the length of the foot, for the purposes of holding on to uneven surfaces, and of more effectually raising the body over the foot and propelling it forwards in the act of walking or running; besides this, they impart elasticity to the step. The lateral arching of the foot occurs in the middle and anterior parts of the tarsus and in the posterior and middle portions of the metatarsus; it contributes greatly to the strength of this part of the frame, which has at every step to bear the whole weight of the body. The marked projection of the heel, 2, gives a great advantage in leverage to the large muscles of the calf. The arching of the foot likewise assists in protecting the important soft parts, namely, the muscles, bloodvessels, and nerves, which are situated beneath it. The bones of the foot are not merely so shaped as to fit together in the form of an arch, like the keystones in masonry, but they are maintained in that position by strong ligamentous bands, passing either between or across the under sufaces of the bones; the short muscles of the foot also con-

Fig. 51.

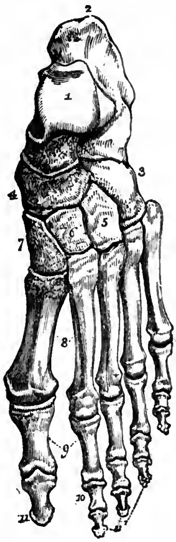


Fig. 51. Dorsal or upper view of the bones of the left foot, showing its great strength, breadth, the parallel arrangement of all the toes, and the great size of the innermost toe. 1 to 7, the tarsal bones. or tarsus; 1, astragalus; 2. os calcis, calcaneum or heel bone; 3, cuboid bone; 4, scaphoid bone; 5, 6, 7, the three cuneiform bones; 8. the five metatarsal bones; 9, 10, 11, the first, second, and third rows of phalanges.

Fig. 52.

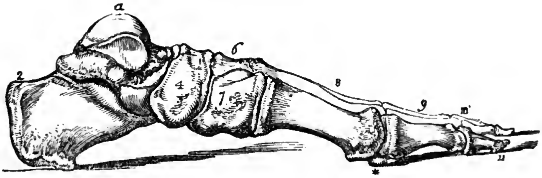


Fig. 52. Internal lateral view of the bones of the foot, showing the strength of the tarsal bones, and of the metatarsal bone of the great toe, the projection of the heel bone, and the antero-lateral arch of the foot. 1 to 7, the tarsus; 1. astragalus; 2, os calcis; 4, scaphoid bone; 6, 7, two of the cuneiform bones; 8, the metatarsal bones; 9, 10, 11, the three rows of phalanges of the toes; * sesamoid bones at the ball of the great toe.

tribute to maintain its arch-like form (see Fig. 4), and even the strong plantar fascia, with its great thickness of fibres, serves not only to protect the soft parts covered by it from injury through the sole, but also contributes to maintain the antero-posterior arch of the foot. Thus constructed, the arch of the foot, strong, and yet elastic, from the gliding movements of its joints, and possessing likewise, without diminution of its strength, a slight lateral motion, at the ball and socket joint, between the astragalus and the scaphoid, is capable of adapting itself readily to the unevenness of the surfaces on which we tread, and also of breaking the shock produced in walking, running, leaping, or other movements of the body.

At the *ankle*, the superincumbent weight of the body is borne upon the broad square surface of its topmost bone, the astragalus, Fig. 52, 1, from which the weight is transmitted in the standing posture, partly backwards through the os calcis, 2, and partly forwards through the other tarsal, 6, 7, and metatarsal bones, 8. The surface of the astragalus is received into the deep quadrangular recess formed by the lower end of the tibia, the inner ankle, or malleolar process of that bone, and the outer ankle, or malleolar projection of the fibula. With the exception of a slight lateral play, which is very limited when the leg is at right angles to the foot, but is somewhat more free when the foot is fully extended, giving a graceful turn to the limb, the chief movement here permitted is of a hinge-like character, in which the tibia, or main bone of the leg, may be said to rock backwards and forwards upon the astragalus.

At the *knee-joint*, the femur can be brought, in standing, in a straight line over the tibia, so that the one bone is supported on the other, like a pillar. The chief points of constructive adaptation here, are the very broad and slightly hollowed surfaces of the upper end of the tibia, the concave semilunar cartilages which deepen the bearing surface of the joint, the large expanded condyles of the femur, the strong lateral ligaments, and the still stronger internal crucial ligaments, both sets being attached behind the axis of motion; and lastly, the protective influence of the patella in front, and also the increased leverage given to the muscles fixed to that bone. The knee-joint, indeed, is the largest in the body, and, from its breadth and strength, is admirably suited to bear the weight, and sustain the shocks, which are continually brought to act upon it. One point, specially noticeable, is the greater length of the inner condyle of the femur as compared with the outer condyle—a formation necessary to establish a *horizontal* line of support, from side to side, between the femur and tibia, at the knee-joint. At the upper end of the femur, the neck is elongated, and placed at an angle with the shaft, so as to increase the breadth of the body for the attachment of muscles at the hips; and in consequence of this, the thigh bones incline towards each other from the pelvis to the knees, so that the leg and foot may be brought more directly beneath the centre of gravity. If, with this inclination inwards of the thigh bone, its condyles had been of equal length, there would either have been a certain interval between the internal condyle and the head of the tibia, or, if the tibia had been elevated at that edge to meet the femur, the bearing surface of the knee-joint would have formed an inclined plane downwards and outwards, and so would have presented a condition of constant insecurity. The great relative strength, and length, of the human femur, are also associated with the firmness of posture, and the rate of locomotion, of man.

At the *hip-joint*, the depth of the acetabulum, especially the overhanging of its upper border, the increased protection afforded by its fibrous rim, the presence of the internal ligament (ligamentum teres), and of the strong accessory ligament over the front of the joint, give great security to this part of the frame; whilst the slightly arched form of the femur, the accumulation of compact bony tissue at the back of this bone, and, we may also add, the prismatic shape of the tibia, and the brace-like provision afforded by the presence of a complete fibula, are evidences of special adaptation in the supporting osseous columns of the lower limb.

The strong hoop-like mass of bone formed by the *pelvis*, is adapted for the steady support of the superincumbent weight of the rest of the trunk, and for the transmission of this, downwards to the thighs; its circular form imparts to it great strength; its inclined position from before backwards, serves to sustain the viscera within it; and the greater thickness of its bony tissue along the lines extending on each side outwards and downwards from the sacrum to the upper part of the acetabula, insures sufficient strength in the directions through which the weight is transmitted from the lower part of the vertebral column to the two hip-joints, and thence to the heads of the thigh bones. The large and projecting surfaces of the pelvis are occupied entirely by muscular attachments, and they afford great leverage for those muscles which pass upwards from the lower limbs, and serve to balance the pelvis upon the thighs.

The great size of the upper part of the sacrum, and its mode of attachment between the innominate bones, the breadth and mass of the bodies of the lumbar vertebræ, the gradually diminishing size of these, and of the dorsal and cervical vertebræ, in passing from below upwards, in accordance with the successively diminished weight which they have to bear, are arrangements evidently in harmony with the erect position of the body (see Figs. 10, 11, 12). The length and breadth of the spinous processes correspond, severally, with the strength of the muscles connected with them at different parts of the spine, serving to increase their leverage and their surfaces of attachment. Moreover, the direction of these, as well as of the transverse processes, is horizontal in the loins and neck, so as to permit of rotatory movements in those regions; whilst, in the back, the spinous processes overlap each other, and the transverse processes are so connected with the ribs, as to impede such rotation, whereas they do not prevent extreme forward bending in that part of the vertebral column. In the neck and loins, the bending of the column takes place chiefly in the backward direction. The presence of the intervertebral substances, Figs. 10, 12, and their effect in imparting elasticity and diminishing shock, have already been noticed. Lastly, the curvatures of the spinal column itself, presenting an anterior convexity in the neck, a posterior convexity in the back, and, again, an anterior convexity in the lumbar region, also increase the elasticity of the vertebral column, and diminish the effects of concussion, the lines of force passing out through various parts of a curve, instead of being continued throughout the whole length of a straight line. The several curves of the spine are, moreover, so adjusted, that, in the erect posture, a perpendicular line from the summit of the movable part of the vertebral column, would fall through the centre of its base.

The peculiar mode of adjustment of the head upon the trunk, Fig. 12, also affords proof of the special adaptability of man to the erect position; for the foramen magnum of the *occipital* bone, is placed farther forward in the base of the skull than in the vertebrate animals generally, showing a special fitness for the support of the head upon a vertical or upright vertebral column, instead of at the end of a vertebral column more or less inclined towards the horizon. In man, the foramen magnum is placed a little behind the centre of the skull, which is, therefore, not quite exactly balanced, but exhibits a slight tendency to incline forwards, when muscular effort is relaxed from fatigue, fainting, or sleep. The absence of prominent ridges on the cranial surface, also indicates that its supporting muscles do not require the advantages of leverage, which they usually possess in animals; the shortness of the cervical spines, and the want of a ligamentum nuchæ, are facts having a like bearing. The position of the mouth, and of the several organs of the senses, especially of the eyes, in relation to the wants of man, also demonstrates his fitness for the upright posture.

Finally, the absolute unfitness of the upper limb, if examined from its single point of bony support at the inner end of the collar-bone to the tips of the fingers, whether considered as regards its position, length, size, shape, or the structure of its several parts, for bearing any share of the weight of the body, affords a negative argument in favor of the intended erect attitude of man.

Thus constructed and adapted for the erect position, the entire body may be regarded as composed of five chief segments, the lowest being formed by the arched foot, the next above that by the legs, and the others in succession by the thighs, the trunk, and the head. Now, the foot affords a base of support to the rest, and, when naked, can grasp the ground by aid of the flexor muscles of the toes. The weight is supported chiefly on three points, viz., the heel, and the anterior ends, or heads, of the first and fifth metatarsal bones. In standing on the toes, with the heel raised, the weight is borne on the ends of all the metatarsal bones generally. Opera-dancers, however, by practice, are able to sustain the weight on the end of the great toe. The next segment of the body, the leg, is balanced on the foot, partly by the extensor and flexor muscles of the leg (see Figs. 4, 5), in front and behind, acting as opponents to each other, but, mainly, by an instinctive adjustment of the centre of gravity over the vertical axis of the tibia. The thigh is similarly balanced upon the leg, also by extensor and flexor muscles; and the pelvis and trunk upon the thigh, by very numerous and large muscles, such as the glutæal, adductor, iliac, and psoas muscles. The spine itself is kept erect by the powerful erectores spinæ muscles, aided, however, by many others. Lastly, the head is balanced on the neck by the complexi, splenii, sterno-mastoidei, and other deeper muscles. At the knee-joint, the crucial ligaments are stretched, as the thigh assumes the vertical position over the legs; they thus retain those bones in apposition, like a rigid pillar, with little or no muscular effort. The ligamentum teres, and the external accessory, or ilio-femoral, ligament in front of the hip-joint (see Fig. 1), perform the same office there. The elastic ligaments connecting the arches of the vertebræ behind, economize, as already mentioned, the muscular power of the erector muscles of the spine. The muscles at the back of the neck, are instinctively relieved by a slight inclination of the head backwards, so as to bring the centre of gravity over the basis of support in the vertebral column.

In thus *standing* erect on both legs, the weight of the body is transmitted perpendicularly through the vertebral column; thence, laterally and obliquely, through the sacrum, to the hip-bones; and thence, through the lower limbs, to the ground. In this position, the centre of gravity is placed perpendicularly over the middle of the basis of support, which corresponds with the surface of the ground covered by the feet, and with that forming the interval between them; a line let fall from it passes midway between the inner ankles. The natural slight eversion of the feet, materially increases the mechanical base of support, over which it is easy to maintain the weight of the body. In *standing at ease*, one leg bears nearly all the weight of the body, whilst the other is simply planted, at a little distance forwards, upon the ground; the trunk inclines over the limb which bears the weight, and a line let fall from the centre of gravity, now passes through the middle of the ankle-joint of that foot; the limb being stiffly extended, the ligaments of the knee and hip-joints are so stretched on that side, as to save muscular power. On the opposite side, the pelvis is lowered, the thigh is bent a little upon it, and the leg a little on the thigh; so that the muscles of that leg also thus obtain some rest. In *standing* entirely *on one leg*, a line from the centre of gravity passes through that limb to the ground; and, unlike the position just mentioned, this attitude demands considerable muscular effort, especially to keep the leg and thigh erect upon the ankle and knee, and to balance the pelvis, which inclines over to the same side, upon the head of the thigh-bone. Standing on one leg soon becomes very fatiguing, not only because the limb has to bear double the usual weight, but because the base of support is so reduced, that more energetic muscular action is needed, in order to keep the centre of gravity in the proper position over it. It has been computed—and it is quoted as an example of the disproportion already mentioned as prevailing between the muscular power expended, and the useful work accomplished—that, in raising the heel, and standing on tip-toe on one foot, the muscles of the calf must develop 80 times more force than would directly counterpoise the weight of the body; so that, if the latter be taken at 150 lbs., the muscles of the calf must exert an effort equal to 12,000 lbs. In the act of walking, as we shall see, the body is partly, and in the act of running, entirely, supported in this way during a certain part of every step.

The act of *walking* is accomplished by means of alternate unsymmetrical movements on the two sides of the body, performed at the ankle, knee, and hip-joint, the trunk being kept, as nearly as possible, in a state of equilibrium, though, as we shall immediately show, its centre of gravity is not merely carried forwards, but undergoes both vertical and lateral oscillations. One leg is first lifted from its base of support, with a slight flexion of the knee and foot, so as to prevent the latter from touching the ground, and is advanced a certain distance, chiefly by swinging, as will be presently mentioned, but also by flexion of the thigh upon the pelvis, and by extension of the leg and foot; it is soon permitted to touch the ground in advance of the body, the centre of gravity at the same time descending a little, as well as advancing forwards, and also inclining over in the direction of the advanced limb. As the forward foot advances, the hinder one inclines in the same direction, and the centre of gravity, now moved beyond the original base of support, is slightly lowered. When the forward foot has touched the ground, the hinder one is raised by extension of the foot, which, continuing to press on the ground, assists in urging the centre of gravity forwards, a little upwards, and still more over to the opposite side. The centre of gravity having now, reached a secure point of support, over the advanced and stationary limb, the hinder limb completely leaves the ground; the thigh is slightly bent on the pelvis, the leg is a little bent on the thigh, and the foot somewhat on the leg; in this position of the segments, it is shortened by about one-ninth part of its length, so that the toes should keep clear of the ground. The limb, in its turn, is now swung forwards, to be planted on the ground in advance of the body, the centre of gravity being again carried forwards, downwards, and over to the same side, and the foot being finally planted on the ground, as before. A repetition of the same movements, with the same results, is performed by the two limbs alternately. Regarding the body as a whole, the centre of gravity is not moved directly forward, at a uniform height from the ground, in any mode of progression. Such a condition does not take place in any living animal, though it happens in the case of inanimate objects, such as carts, locomotives, or masses of matter dragged over horizontal surfaces. In the living body, to advance implies an elevation of the centre of gravity, followed by a slight descent: in other words, the body is lifted and falls at every step forwards, and so describes a vertical oscillation, which has been estimated at about one inch and a quarter in extent. As above shown, lateral oscillations also occur, due to the alternate shiftings of the centre of gravity from a point over one leg to a point over the other. In walking, the advancing foot invariably touches the ground, before the hinder foot is lifted; so that in this mode of progression, there is a short period, during which both limbs touch the ground, alternating with a longer period, in which only one limb rests upon the base of support. The general rate at which man can walk, depends on the length of his lower limbs, the thigh being unusually long. The pace, in particular cases, is regulated by the length of the leg, and by the muscular efforts employed to secure rapidity of step. In rapid walking, almost every muscle of the body is exercised; the duration of the step is shortened, and so also is the length of time during which both feet touch the ground together; the length of the step may be either shortened or increased. In the case of a man, walking at the rate of 4 miles an hour, and whose legs were 34 inches in length, the number of steps taken in 15 minutes was 2000, the length of each step 2.64 feet, and the period of each step .45 of a second (Vasey). In very quick walking, the rate has been nearly $5\frac{1}{2}$ miles per hour, or about 7.9 feet per second. It has been shown that, whilst in slow walking, the advancing limb performs as complete an oscillation as its length will permit, and is off the ground for two-thirds of a second, in very quick walking, and in running, the limb performs only half an oscillation, but in much less time, that is, in less than half a second: again, in slow walking, the supporting limb is in contact with the ground one-third of a second, but, in quickened walking, a shorter and shorter time, until at length, in running, the duration of such contact is only a small fraction of the time in which the other leg is swinging.

To the act of *running*, which, like walking, consists of unsymmetrical movements, there is a transition from rapid walking, in the step known as "the double." In true running, which might perhaps be confounded with quick walking, the distinguishing character is that both feet are never on the ground together, the hinder foot being raised a brief interval before the advancing foot comes to the ground; so that in running, there is a short interval, during which one foot only is on the ground, and then a longer interval in which both feet are off the ground, and the body, instead of being alternately propelled, is continuously swung forwards in the air. The centre of gravity not only advances, but oscillates in the same manner as in walking, the curve described in ascending and descending, varies from three-quarters of an inch to an inch and a quarter, and the lateral oscillations are less than in walking, in consequence of the advancing foot being brought more nearly under the middle line of the body. In running, it has been shown that, just as the forward foot reaches the ground, the centre of gravity is exactly over it: an arrangement necessary to counteract the tendency of the body to fall forward, which is very much increased at high velocities; if the foot is prevented advancing, as in the act of tripping, then the person either stumbles or falls. In any increase of pace, whether of walking or running, the mean height of the centre of gravity is often slightly diminished by an increased flexion of the lower limbs, which also increases the possible length of the step. The ordinary rate of quick running is about 10 miles an hour; but, for short distances, the rate may be 13 miles an hour, or about 18.8 feet in a second.

In both walking and running, it has been found that the trunk is inclined forwards from the vertical line at an angle, which gradually increases as the step becomes more rapid. In both progressive movements, too, the lateral disturbance of the centre of gravity, which depends on the alternate forward movement of the lower limbs, drags the pelvis first after one and then after the other limb, and so leads to a rotation of the trunk. This is compensated for, or counteracted by, a corresponding forward movement of the *opposite* arm, accomplished not by muscular exertion, but by a swinging or pendulum-like action which serves to restore the balance of the upper part of the trunk. It has likewise been shown by the brothers Weber, to whom we are indebted for most of our knowledge on this subject, that the forward movement of the lower limbs, though guided by the muscles, especially in the maintenance of such a length of the limb and elevation of the toes, as will prevent these from striking the ground, is, mechanically considered, and in the main, a pendulum motion; and that the weight of the limb itself is, in part, supported, as already explained, by the pressure of the atmosphere transmitted to the hip-joint. The full swinging movement of the lower limb, allowance being made for the forward motion, through space, of the acetabulum, or point of suspension, is almost exactly equal to the oscillation of a pendulum of the same length, at the same part of the earth's surface, both in extent and velocity. The economy of muscular power thus obtained, is sufficiently obvious.

In *leaping* from both feet, the muscular acts, unlike those performed in walking and running, are symmetrical on the two sides of the body. The centre of gravity is first lowered considerably, by the bending of the joints of the lower limbs, and by leaning forwards with the trunk; in this position, a line let fall from the centre of gravity, passes down through the balls of the toes, from a point anterior to the sacro-lumbar articulation, in consequence of the forward projection of the head and arms. By the sudden and violent contraction of the extensor muscles of the lower limb, which are much stronger than the flexors, that is, by the powerful action of the muscles of the calf, of those in front of the thigh, and of the gluteal and other muscles at the back of the hip, the more or less acute angles formed at the ankle, knee, and hip, are simultaneously opened, and the centre of gravity is lifted upwards, or upwards and forwards, according to the inclination of the trunk, or to the special direction of the impulse. Leaping consists, therefore, of a series of jerks of the body, produced by single powerful efforts. In leaping, the legs are first drawn after the body, but they soon advance forward to receive the descending weight; and leaping is distinguished from running, in this: that the centre of gravity is raised so high, and for so long, in the air, that the lower limbs are able to complete their forward oscillation, and so accomplish a very long step or leap. In the combination of leaping with running, the velocity of the body acquired in the former act, is superadded to the impulse of the leap, and so the total length of the spring is increased. The forward impulse of the body is shown by the movement of the arms in alighting. Hopping is performed on similar principles to the leap, but the spring takes place from one leg only.

There are some other movements which need not be particularly described, such as creeping, and climbing, or letting one's self down a rope or tree. Swimming is a special mode of progression, which will be presently noticed.

Locomotion of Animals on Solids.

In the higher Quadrumana, generally, the attitude of the body, in ordinary progression, is semi-erect, and in the very highest, especially in the gorilla, if recent observations be correct, an almost perfect erect posture and gait can be temporarily maintained, without any support from the anterior limbs. In continuous and rapid progression, however, even this animal leans forward, and shambling along, supports the weight of the fore-part of the body upon its long anterior extremities, touching the ground alternately with the back of the knuckles of one or other hand, and moving therefore in a half-biped, and half-quadruped, mode of progression. Neither in the gorilla, orang, or chimpanzee, does the skeleton exhibit that perfect adaptation to the erect posture which is seen in man. The feet, though entitled, from their function, to the designation of hands, as implied by the title Quadrumana, are, nevertheless, anatomically constructed after the manner of the human foot, and not after the fashion of the hand. But the foot of the ape is far less perfectly adapted to bearing weight than that of man. The tarsus, metatarsus, and phalanges, are proportionally narrower and longer; this narrowness is due partly to the general slenderness of the four outer metatarsal bones and their phalanges, but also to the altered size, position, and form, of the great toe, which ceases to be the largest toe in the member, and is no longer placed parallel with the other toes, but is very much shorter and smaller, stands inwards from the rest, and in these respects, as well as in its form and opposability to the other toes, closely resembles a thumb; in the orang, it ceases to possess a long flexor muscle. Moreover, the os calcis, in most of the apes, is small, less projecting, straight, and somewhat raised from the ground; the arch of the foot is less pronounced, and it is so articulated with the leg, that it is not fairly applied to the ground by the sole, but, more or less, by its outer border. The foot of these creatures, indeed, is not a hand, but rather a grasping or prehensile foot; and, in certain men, this character, as manifested by the slight opposability of the great toe, is not entirely absent. In descending the scale, the foot is still more slender and prehensile, the great toe is further reduced in size, has no independent action, and the foot departs more and more from its human character, ultimately being adapted only for mere *clasping*, as in the spider monkeys. Besides this, in the Quadrumana, the bones of the leg are more or less bowed; and in the ordinary position of the tibia, femur, and trunk, in standing, these segments of the animal's frame, are placed at angles to each other, and do not rest in the form of an erect perpendicular column; the surfaces of the knee-joint are comparatively small; and the entire lower limb is not only weaker, but altogether shorter, than in man; whilst the arms are lengthened, in various proportions, in different species, so as to enable them to reach the ground. The pelvis is narrower, longer, and weaker. The vertebral column does not present that marked threefold curve which it has in man: nor do the vertebræ exhibit that gradual increase in size from below upwards, which they present in him. In the gorilla, orang, and chimpanzee, there are only four lumbar vertebræ; the number of dorsal vertebræ bearing ribs is thirteen in the gorilla, twelve in the orang, and thirteen in the chimpanzee. The surfaces of the bodies of the vertebræ generally, are inclined to the horizon; and their spinous processes are more powerfully developed than in man, to enable the posterior or erector muscles to support the habitual forward inclination of the body. These characters of the spines are particularly noticeable in the upper dorsal and lower cervical region, where they afford increased surface of origin, and greater leverage, for the muscles intended to support the head. The cranium itself has its occipital foramen, and adjoining condyles for articulation with the neck, situated further and further back, as we descend in the Quadrumanous scale; so that the weight of the head is carried at a mechanical disadvantage, as compared with man; a disadvantage counterbalanced by the greater development of the spinous processes, and of the posterior cervical muscles. In the lower Quadrumana, such as the ateles or spider monkey, the attitude and mode of progression, on the ground, become more decidedly horizontal; the anterior and posterior limbs being now of nearly equal length, and the hands and feet almost exactly resembling each other in form. In the lowest, so-called, Quadrumana, as in the Lemurs, the erect, or partially erect, position, is only momentarily possible, and progression in that attitude never takes place; the great toe ranges with the others, and bears a claw.

In the Anthropoid apes, the centre of gravity is placed higher up in the trunk than in man, owing to the comparative shortness of the hinder limbs, and the greater proportionate length of the anterior ones, as well as to the forward inclination of the trunk. In the lower Quadrumana, the centre of gravity advances still further forwards, approaching its normal position in the quadruped.

In the Quadruped mode of standing and locomotion, the intrinsic power is, as usual, obtained by muscular force, exerted upon movable levers, having their points of support and resistance upon the ground. Their progressive motion is compounded of the results of muscular force and gravity. Owing to the near approximation, in length, between the fore and hind limbs, and to the larger development and greater length of the neck and facial part of the head, to which the prehensile functions are now transferred, the centre of gravity of the whole body is advanced forwards, and is placed somewhere about the middle of the thorax, a little behind the junction of the fore-limbs with the trunk. It is mainly in consequence of this forward position of the chief mass of the body, that is, of its centre of gravity, that a quadruped animal experiences such difficulty in the act of rearing, and cannot long maintain that position. The size of the muscles of the hinder limb, the nature of its joints, the angular position of its segments, and the narrowness of its base of support at its extremity, also occasion this difficulty; whilst the mechanism of the vertebral column, the absence of that gradual increase in size of the bodies of the vertebræ from the neck to the lumbar region, the comparative small amount of intervertebral substance, and other peculiarities, such as the absence of the triple vertebral curve, and the relative size of the pelvic and spinal muscles, display a want of adaptation for the erect posture, and a fitness of the trunk for the horizontal attitude. The position of the head at the end of the neck, and the development of the dorsal and cervical spinous processes, also show an express adaptation to this horizontal position. The trunk of the body, especially its thoracic part, is now compressed from side to side; and the anterior limbs are attached near together on the under side of the trunk, the weight of the fore part of which is thus more easily supported. The hinder limbs are moderately thrown out above at the pelvis, but are also inclined towards each other where they reach the ground, so as to bring the base of support there also under the weight to be carried.

In *standing*, in the quadruped position, owing to the forward situation of the centre of gravity, a greater amount of weight is carried on the anterior than on the posterior limbs, the weight not being equally divided between them, as might, without consideration, appear to be the case. In the most perfect forms of quadruped *progression*, as, for example, in the active Ruminants (stags, antelopes, &c.), and in the Soliped Pachydermata (horse, zebra, donkey), the fore limbs are brought very near together under the body, there being no collar-bone to thrust them outwards from the sternum; owing to the absence of this bone, moreover, the fore limbs are attached to the trunk by muscles only. The chief muscle is called the great serratus (represented, in the human body, at 5, Fig. 4), which, arising by many heads from most of the ribs low down, passes upwards, in the quadruped, towards the scapula, into which it is inserted; by this arrangement on the two sides, the trunk of the animal may be said to be suspended in a sort of muscular sling, composed of the two large serrati muscles, which spring from the thorax, and are attached to the scapula, or upper segment of each anterior limb. The posterior limbs, on the other hand, are connected by articulations with the pelvis, and the pelvis similarly with the vertebral column; so that here the weight of the body is transmitted directly from bone to bone. These differences between the modes of connection of the fore and hind limbs, have reference to the offices of those limbs in progression. The hinder limbs, with their segments inclined more or less at angles to each other, and provided with powerful muscles for unfolding those angles, and so straightening and increasing the length of the limbs, are concerned mainly in giving the forward and upward impulse to the body of the animal over the ground. The anterior limbs, besides assisting in the progressive movements, have also, and chiefly, to receive and check the downward course of the centre of gravity lying in the anterior part of the body; the segments of this limb are, accordingly, straighter, or less angular, than those of the hinder limb.

In the larger and heavier quadrupeds, such as the elephant, rhinoceros, and hippopotamus, the segments of the limbs are shorter, thicker, and more perpendicular in their direction; peculiarities which increase the bearing powers of the limbs, but diminish their locomotive capabilities, as manifest in the slower and more unwieldy actions of those bulky creatures. In the Equine, and more active of the Ruminant, animals, the limbs are proportionally more slender, longer, and have the segments placed at more acute angles, especially, as already noticed, in the hinder limb; of these, however, the horse is the best fitted of all quadrupeds for rapid and energetic motion, and for draught, and constitutes the exemplar of quadruped locomotion. The Flying Childers ran at the rate of 4 miles in 6 minutes and 2 seconds, or about 40 miles an hour, whilst the pace of Eclipse was 56 miles an hour, or nearly a mile in a minute. This swiftness of the horse is mainly owing to the solidity of the extremities of its limbs, which consist of an enlarged and expanded single toe, or finger, which carries the broad and solid hoof. In the heavier Pachydermata, the toes are more numerous, being three in the rhinoceros, four in the hippopotamus, and in the elephant five, inclosed in one mass; but the foot, though broader for carrying weight, loses in firmness. In the cleft foot of the Ruminants, the number of digits is four, two bearing the proper bisulcate hoof, and two the spurious hoofs; the parts of the foot are thus easily spread out, so as to give a greater hold upon soft ground; but it exhibits a proportionate degree of weakness.

The movements of quadrupeds are named the walk, the amble, the trot, the canter, and the gallop. In the act of *walking*, a quadruped first moves forward one fore-leg, and then the opposite hind-leg; next the other fore-leg is advanced, and then the opposite hind-leg, and so on; these several movements being perfectly distinguishable, and following in regular sequence, however rapidly the animal may walk. The centre of gravity not only moves forwards, but rises and falls, and moves obliquely from side to side, according as the one or the other fore-foot is being advanced; moreover, one foot only is off the ground at the same moment, the advancing fore-foot always being placed down before the opposite hind-foot is raised, and the latter being placed down before the opposite fore-foot is raised. In *trotting*, the fore and hind limbs of the opposite sides, are advanced simultaneously, and they are raised from the ground, and placed upon it again, also simultaneously; so that the centre of gravity is supported alternately upon the right fore-leg and left hind-leg, and then upon the left fore-leg and right hind-leg; and in this movement there is much less lateral oscillation, indeed scarcely any at all, in comparison with the walking movement, as the rider on horseback practically knows. In *galloping*, both fore-legs are lifted from the ground almost simultaneouly, and the body of the animal is projected upwards and forwards, by the extension of both hind limbs; the weight of the body then descending, is received on both fore-legs, which are brought to the ground again, almost at the same instant of time, when the hind-legs are once more brought under the body, and placed almost simultaneously upon the ground, so as to be ready for the performance of another spring. *Cantering* is a sort of a slow, measured gallop, in which a longer interval of time elapses between the placing of the two fore-legs and the two hind-legs upon the ground. In the canter one or other pair of legs only, is raised from the ground at any one instant; so that the body of the animal is always supported by one or other pair of limbs; but in the gallop, there is a period, short in the slow gallop, but more and more prolonged in the rapid gallop, as in the active strides of a race-horse, when all four limbs are off the ground, and the animal is swinging in the air.

In the Carnivora, the mode in which the feet are used in progression, has led to a threefold division of that class into the digitigrade, such as the cat and dog tribes; the plantigrade, represented by the bears; and the palmigrade, natatory, or swimming Carnivora, exemplified by the seals.

Amongst the quadruped Mammalia, a well-marked distinction may be drawn, as regards their locomotive powers and habits, between those which possess a clavicle, and those which do not. As already stated, in the larger quadrupeds, moving like the horse, zebra, and donkey, there is no clavicle, as in the rhinoceros, elephant, hippopotamus, hog, ox, giraffe, camel, stag, antelope, goat, sheep, and other Ruminants. In all such animals, it is to be noted that the anterior limb is used exclusively for purposes of locomotion, or for those of offence or defence; but it has no prehensile faculty. In a great number of the four-footed Mammalia, however, the anterior limb has a prehensile character, or is used in some special manner adapted to the habits of the animal, in addition to its mere locomotive function; in such cases, a collar-bone, more or less perfectly developed, is found. Thus, in the Carnivora, in which the anterior limb is used in striking or seizing the prey, a short, imperfect collar-bone is found, which is smaller in the dogs and larger in the cats; in the seal tribe it is absent. A slender collar-bone exists in certain Rodentia (as the rabbit, hare, and rat), which use their anterior limbs in scraping and burrowing; and in the squirrel, which can climb, seize, and hold nuts and other food in its fore-paws, the clavicle is well developed. In the Cheiroptera (bats) the anterior limbs are organized for flight, and also have a clavicle, which is long, strong, and bent. This bone is likewise present, and strongly developed, in the burrowing Insectivora, being short, broad, and cubical in the mole; it is also large in the Edentata (armadillo, ant-eater). Even in the low Marsupials (as the kangaroo), which have considerable prehensile power in their comparatively small fore-limbs, the clavicle is present. In this creature, the quadruped mode of progression is only occasionally employed; but its more active movements consist of powerful leaps, which it performs by the sudden extension of its large hinder limbs, and by the flexion of its powerful tail, the muscles of both of which parts are enormously developed; there is a sharp claw on the large fourth toe, which is used to tear open the flank of an attacking animal. With the kangaroo, a very common attitude is a semi-erect position, maintained by resting upon the hinder limbs and tail. The squirrel, likewise, uses its large bushy tail, both as an organ of support in sitting, and also in leaping.

A still further deviation from the ordinary mode of progression on land, in Mammalia, is witnessed in the seals, which animals, when out of the water and moving over the ground, accomplish this, partly by a feeble and awkward motion of the anterior paddle-like limbs, and partly by a wriggling motion of the hinder portion of the body. The Cetaceans probably flounder still more helplessly upon the ground.

In Birds, the attitude upon, and mode of progression over, solid surfaces, is biped, or as in the case of many birds, whilst resting or actually sleeping, the standing position is accomplished upon one leg only or is uniped. The centre of gravity being situated very far forward in the body of a bird, owing to the great size of its pectoral muscles and wing bones, the trunk is usually held, in the standing position, inclined very little from the vertical direction, so as to bring the weight more over the base of support in the soles of the feet. The lumbar and dorsal regions of the vertebral column are very strong, and exhibit but little power of bending. To aid in supporting the weight, this base is extended forwards by the elongation of the phalanges of the toes; and to give the necessary rigidity to the trunk, the pelvis and lumbar region are solidified together, whilst the dorsal vertebræ are capable only of comparatively slight motion, the respiratory movements being performed rather by the descent of the sternum, than by any expansion of the ribs; the neck also, which is usually long in birds, to suit the prehensile character of the bill, is capable of being folded back over the trunk, so as to bring its weight over the base of support; the wings, as usually folded in walking, also serve to transfer weight to the hinder part of the body. In standing on a level surface, the weight of the bird is transmitted through the elongated metatarsal bones, and is then distributed through the several toes, the length of which varies in different species, according to the hardness or softness of the ground on which, in accordance to its habits, it usually has to run. In other instances, the foot is better suited for grasping more or less prominent surfaces, or even the trunks and smaller boughs of trees, bushes, or other plants; in which case, the toes are shorter and stronger. In some scansorial tribes or climbing birds, one of the three toes, which in other birds are turned forwards, is, at the will of the bird, or else permanently, turned backwards, so that there are two toes in front and two behind, an arrangement which gives great holding power. Many birds habitually perch upon boughs or branches, and in them the foot possesses a very perfect prehensile power; and, by a peculiar arrangement of the tendon of the flexors of the toes, when the weight of the animal bends the tarsus upon the leg, the tendon is stretched mechanically over the heel, and so serves, without further muscular effort, to tighten the whole of the toes upon the object which they grasp; moreover, on simply raising its weight, by extending the hinder limbs, the hold of the toes is simultaneously loosened, independently of any proper extending effort. In birds which sleep whilst perching, this mechanism is constantly employed, in certain instances, the animal sleeping securely by resting on, and grasping with, one leg only. The folding back of the head under the wing, an attitude so suggestive of repose, retirement, and reliant security, fulfils the further purpose of aiding in the easy preservation of the equilibrium of the body, by removing backwards the centre of gravity more completely over the now single base of support. There are certain birds of the crane-tribe, which have very long legs, and moderately prehensile toes, which still balance themselves in the daytime habitually on one leg, whether they sleep or not; in these cases, too, the head is drawn back under the wing, the centre of gravity is placed probably over, or nearly over, the column of support, and this is kept vertical by the extreme extension of the tarsal joint, and its stiffening by ligamentous connections.

A certain number of small birds seem to have no power of walking, but invariably hop over the ground, a movement which may be compared, in regard to its mechanism, with the leap in man; but most birds whether large or small, can either hop or walk; the latter motion is much more frequently employed, and resembles the walking mode of progression in man, the action of the bird being truly biped, although the weight is supported on the phalanges and metatarsus, and not on the tarsal bones also. The running birds perform that movement on the two feet, alternately, as in man; and, in the case of the larger cursorial birds, as the ostrich, for example, the rate and endurance of the motion are very great; the speed of the ostrich is, indeed, said to be as high as that of the race-horse, and the great length and size of its lower extremities, and the diminution in the number of its toes, which, in some species, are only two in number, add, as similar arrangements do in the horse, to the solidity and security of the foot, as an organ of support and locomotion. The peculiarities of the lower limbs in climbing birds, have already been noticed; in that action, the limbs are moved alternately, as in running.

In the four-footed Saurian Reptiles, the crocodiles, alligators, lizards, and others, the movement is essentially quadruped in its character and mechanism; but, with the exception of certain active lizards, and even they cannot long maintain their celerity, the motion of these animals is heavy and awkward; this is owing to the shortness of their limbs, the imperfect modelling of the articular surfaces of the bones, and the comparative want of energy in their muscular system; and something is also due to the length of their unwieldy body between the anterior and posterior limbs, and to the lateral position of the points of attachment of the limbs. In the apodous or footless reptiles, the Ophidia, or snakes, the body is no longer raised from the ground upon limbs, but its weight is supported on the under, or abdominal, surface of the trunk, and though the centre of gravity here occupies, as in all masses of matter, a single point, the weight is supported on an enormously long base, corresponding with almost the width and length of the animal, the head and adjoining part of the neck, however, being, as a rule, lifted from the ground. The manner in which serpents move over solid surfaces is threefold. First, they may fix the anterior part of the body, and drag the trunk after it, and then, again, project and fix the fore-part, following this by a second advancement of the hinder portion; this is called the geometric method of progression. Secondly, the animal holds upon the ground by successive portions of its abdominal surface, and throws the intermediate parts into slight vertical undulations. Lastly, and much more habitually, holding in the same way by its under surface, it throws the body into *lateral* undulations, and so advances over the ground. The mechanism concerned in these movements consists, first, of the extremely movable and flexuous vertebral column, in which the lateral play is commonly far greater than the vertical; secondly, of the intercostal muscles acting upon the ribs, which represent long levers attached to the sides of the vertebræ; and thirdly, of certain transverse cuticular plates, situated on the abdominal surface, attached at either end to the extremities of the corresponding pairs of ribs, covered with strong epidermis, and named the abdominal *scutæ;* these scutæ are imbricated, each overlapping the one behind it, so that their free edges are directed backwards; and, when elevated by proper muscles, they take a powerful hold upon the ground, or upon other surfaces, such as projecting rocks, and the trunks and boughs of trees. Certain serpents coil themselves up into concentric rings, and then, resting the tail firmly upon the ground, holding by their scutæ, rapidly unfold their spires, and dart themselves for a certain distance through the air. The extraordinary locomotive powers of serpents, which can glide, or creep, or climb, or swim, or even spring, through the air, are very remarkable, especially when their apparent locomotive inferiority, in the total absence of limbs is considered. In the Chelonian Reptiles, or tortoises, the gait is slow and labored, owing to their wide-spread, and laterally attached, limbs, the shortness of the levers of which these are composed, the comparative feebleness of their muscles, and the great proportionate weight they have to carry; the tortoise is proverbially slow. The turtles walk still more awkwardly, their extremities being adapted rather as paddles for swimming purposes.

Amongst the Amphibia, the motion is quadruped in the frogs, toads, and newts; but in the more defective species, as the proteus, the movement is rather of a creeping kind, the body being supported on its under surface. The energetic leap of the frog is due to the great comparative length and strength of its hinder extremities; whilst the position of the animal, inclined at about an angle of 45° from the horizon, is that which is best adapted for obtaining the longest trajectory over the surface of the ground, with a given expenditure of power. The toads, which hop much more feebly, and often walk or run, have the body placed more horizontally and the hinder limbs shorter than in the frog.

Amongst Fishes, the eel, in its migrations, sometimes crawls over soft mudbanks or grass, moving by lateral undulations, after the manner of a serpent, but much less easily, as it has no abdominal scutæ. There is a species of fish, the Anabas, of Tranquebar, which occasionally leaves the water for a time, and even ascends the trunks and branches of neighboring low trees, accomplishing this by means of its pectoral and abdominal fins, which are, in fact, its anterior and posterior limbs. This animal is provided with a number of large cells on the side of its head, in which it can receive and carry a supply of water for its gills during its temporary aerial journey from its proper element.

Passing now from the Vertebrate to the Molluscous subdivision of the animal kingdom, we find comparatively few of this group which move over solid surfaces. The air-breathing terrestrial Pulmogasteropods (snails, &c.) creep over a solid surface by means of their muscular foot, which adheres closely, without the intervention of air, to the object to which it is attached, moving over it by means of longitudinal undulations, so minute and rapid, in some cases, as to require a magnifying glass for their detection; they may, however, be easily seen by watching, through a common lens, the under surface of a small slug or snail, creeping up a piece of glass. Certain Lamellibranchiata (the pectens) can project themselves from the bottom of the ocean, a short distance through the water, by means of a strong curved foot, which they thrust from their shell in a bent direction, and then suddenly straighten. Others have the power of turning themselves over, or dragging themselves along, step by step, by fixing and contracting a long muscular appendage.

The Molluscoida present no examples of motion on solids.

In the Annulose animals locomotion over solids is a characteristic mode of progression, as in Insects, Spiders, Crustaceans, Myriapods, and Worms. In the higher forms this is accomplished by means of limbs, many in number, provided with numerous joints, and acted upon, after the manner of levers, by powerful muscles. These muscles, however, as seen as in the familiar example of the crab, are contained within the moving levers, instead of the levers being situated, as in the Vertebrata, amongst the muscles, and covered by them. These internal muscles of the Annulosa are really a highly developed system of subcutaneous muscles, connected with the calcareous, horny or chitinous, coriaceous, or soft, integument, as the case may be; they are homologous with the panniculus carnosus or hypodermal muscles of the Vertebrata, and have no relation to the skeletal muscles of the last-named animals. The order in which the limbs of the higher Annulosa move is absolutely definite for each class of these animals, and differs, according to the number of the limbs; thus, the Insects, having six legs, move after one mode; the Spiders, having eight legs, follow another; the Crustaceans, some of which have ten legs, have another; and the Myriapods, or many-footed creatures, a fourth mode. Without diagrams these could hardly be made intelligible. In the Annelids, or Worms, the movement over solid bodies is accomplished, either by fixing the anterior extremity with the mouth, and drawing up the hinder one, and so on continuously, as in the leech; or a holding power is obtained by minute setæ, or bristles, set outwards and backwards, as in certain worms. In these cases the extension of the body in a longitudinal direction is accomplished by the contraction of numerous circular muscular fibres, which surround the body; whilst its required contraction in length is brought about by the relaxation of these circular fibres, and the shortening of other longitudinal bands. Caterpillars move on a similar principle, but are provided with broad suctorial or clasping posterior feet, as well as with the characteristic three smaller, pointed and prehensile, anterior pairs. The numerous special contrivances exhibited in the extremities of the feet of the perfect insects and spiders, would require volumes to describe; sometimes they present hooklets (beetles), sometimes suctorial apparatuses (flies), and sometimes special adaptations, as in the spider, for holding upon webs. A great variety of special modes of locomotion may also be here alluded to, as the jumping of certain spiders the astonishing leap of the flea, and the peculiar sideward mode of progression of certain spiders, and of the crabs; but for illustrations of these, and similar cases, reference must be made to works on Natural History.

Amongst the Annuloida, the Scolecida present a number of creeping animals. In the Echinodermata, which are entirely marine, there is in many species, as in the Sea-eggs or Echini, a remarkable power of locomotion over the bottom of the sea, accomplished sometimes by so-called spinigrade progression, that is, by the motion of long spines, articulated with their shell, and moved by little muscles; in other cases, as seen in Star-fishes, a cirrhigrade progression is performed by the protrusion and working of numerous suctorial tubular cirrhi or feet, which are projected by being filled with fluid, forced into them by special muscular sacs lodged in the interior of the animal; by means of these, the star-fish will even creep up the glass side of an aquarium. In the soft Echinodermata, the Holothurida, the progression is of a mixed character, being cirrhi-vermigrade.

The Cœlenterata have no power of locomotion over solids, being entirely swimming animals; but amongst the Protozoa, the suctorial mode of progression over solids is exemplified in the Rhizopods, as in the simple proteiform Amœba.

Locomotion of Man in Fluids.

Owing to the lighter specific gravity of the human body, when the lungs are expanded, as compared with water, man is able to swim in that element, whether salt or fresh, with a small part of his frame above the surface. When the lungs are fully inflated, the body is lighter than water; after a complete expiration, it is heavier; but in an ordinary expiration it is about the same weight, bulk for bulk: hence, when the chest is fully inflated, a man may float with a small part of his body above water; but by a slight muscular effort, the head may be so thrown back, that, in this state, the mouth, nose, and eyes remain above the surface, but any unusual expiratory act is followed by the submergence of those parts. The smallest exertion of the feet in a treading motion, suffices, however, even under these circumstances, to keep the face above the surface; and, if aided by the hands, this is still more easily accomplished. The buoyancy of the body is however so slight, in other words, its specific gravity is so little lighter than that of water, that, to maintain the face above the surface, every other part must be submerged; for if, whilst thus supported, one arm be extended out of the water, the head immediately sinks in a corresponding degree.

In the act of *swimming*, the body lies, with the abdomen downwards, in, but near the surface of, the water, and not quite horizontally, the head being inclined somewhat upwards, and thrown back, so as to sink as much of the hinder part of the cranium as possible, and to throw the face alone, with the breathing apertures, the nostrils and mouth, upwards and forwards out of the water. A progressive motion is then accomplished, by placing the hands together in front of the sternum, darting them forwards in the middle line, and then sweeping them outwards, with the fingers in contact, and the palms everted and turned slightly downwards, through a part of a circle, and lastly, bringing them quickly inwards to the front of the sternum again. In the meantime, whilst the arms are being extended forwards, the legs are drawn under the body, close together, with the feet extended, and then, are thrust powerfully backwards and outwards, with the feet flat, at the same moment that the arms describe the part of a circle backwards. The combined propulsive action of the anterior and posterior limbs, moves the body forwards, and slightly elevates the head at each stroke; at this moment, inspiration and expiration should be accomplished. Swimming may also be performed on the back, with all four limbs, or on the side, using only one arm, but both hinder limbs. These modes of swimming are less rapid, but quieter, easier, and less exhaustive, than the ordinary mode on the face. The rate of motion of a swift swimmer is surprising, especially when it is considered that the rounded form of the human body is not well adapted for cleaving the water.

Locomotion of Animals in Fluids.

In *swimming*, land quadrupeds generally have this advantage over man, that, owing to the length of their neck, they can more easily maintain the orifices of the respiratory passages above the water. They also swim by an action of all four limbs, precisely similar to that which they habitually employ in locomotion on land, so that no training, as it were, is necessary for them in the art of swimming, but they swim quite naturally on first entering the water; whereas in man, the movements performed in that act, are so special and so different from the ordinary movements of locomotion, that he requires instruction and practice to accomplish them successfully; hence a land quadruped, when thrown for the first time into water, swims with tolerable ease and certainty; whereas a human being, if uninstructed, even if he succeeds in floating, cannot accomplish any definite progressive motion through that fluid.

Certain quadrupeds fitted for an amphibious mode of existence, such as the otter, beaver, seal, and water-rat, have their limbs specially adapted for that purpose. In the two last-named animals, the feet are small, and the toes partially webbed; in the otter, the toes are distinctly webbed; in the seal, the anterior limbs are altogether paddle-like, the integuments extending quite up to the last phalanges; the hinder-limbs are placed almost in a line with the body, and are used somewhat like the tail of a fish.

In the Cetacea, which, though breathing by lungs, are adapted entirely to living in the sea, or the mouths of rivers, the swimming action is, in a few cases, aided by short, paddle-like, anterior limbs (dugong), but it is, in all, mainly effected by powerful alternate movements of the trunk and tail, which strike the water upwards and downwards like the body of the flat fishes, and not laterally like an ordinary fish. The caudal fin-like expansion of the cetacean has accordingly its surfaces directed upwards and downwards, instead of laterally, like the fish.

The specific gravity of birds, with their feathers perfect, is, as a rule, less than that of water. This is owing to the large proportionate size of their respiratory organs, the lightness of their bones, the cavities of which are very large, though filled with fat instead of air in most swimming birds, and lastly, to the quantity of air which is entangled in their down and feathers, and held there, because the oily secretion with which they cover themselves, prevents its displacement by the water. Hence birds of this kind are so buoyant on the water that a much smaller proportion of their body is submerged than in the case of quadrupeds or of man. The form of the body, too, is suitable for floating, being boat-like, and so curved at the fore part, and gradually narrowed behind, as to present but slight resistance to the water, and the smallest amount of friction in the displacement of that fluid behind. The legs of swimming birds are placed further back, and wider apart, than in land birds, and are articulated in such a direction, as to spread away from the body, arrangements calculated to give lateral play to the actions of the feet, and to increase the efficacy of their propelling power over the body; moreover, the tarsi are flattened sideways, so as to present the smallest possible resistance in being moved forward through the water; whilst the phalanges of the toes, also long, compressed, and, when flexed, folded very flatly together, spread out widely when extended, and are more or less completely webbed, so as enormously to increase the power of the stroke in the water in swimming. This stroke is backwards and a little outwards, so that both the limbs act on the water, along two lines diverging outwards and backwards from the middle of the pelvis of the bird, the water reacts in the opposite direction, and the converging forces thus obtained are combined, according to the rule of the composition of forces, into a resultant force, which impels the body directly forwards.

Swimming birds are ungainly in their walking gait, the backward position of the legs necessitating a more horizontal position of the trunk; the great width between the legs, the looseness of the joints, and the softness of the feet, give them a waddling and feeble motion in walking. Diving birds have generally the centre of gravity of the body situated further back than other birds, the head, neck, and anterior part of the trunk presenting a narrow or pointed form; besides the impetus with which they throw themselves into the water, these birds aid themselves by movements, not only of their feet, but also of their short and almost paddle-like wings.

A large number of the Saurian reptiles swim perfectly well in water, mainly by lateral strokes of the hinder part of the body and tail, the latter being usually more or less flattened sideways for that purpose, and acting in the same manner as a fish's tail. In some cases, as in the crocodiles, the nostrils are placed at the tip of their long muzzle, so that they can completely submerge themselves, with the exception of the nostrils. The Ophidian reptiles can probably all of them swim, the water-snakes enjoying that faculty, however, in an eminent degree; in this movement, the head of the snake is raised above the surface of the water for respiratory purposes, whilst rapid lateral undulations of the body are effected, by means of which the water is struck obliquely backwards by a series of flexures, at intervals, on one side, and by another series of flexures on the other side; and the resultant action is represented by two oblique lines diverging, outwards and backwards, from the middle part of the elongated body; but the forward lines of reaction of the water on each side, converge, and meet in the body, so that the resultant force of all the lines of reaction on the two sides, impels the animal in an intermediate direction, that is, directly forwards. The Chelonian swimming reptiles (turtles) move in the water by means of both pairs of limbs, which have a paddle-like shape, and a lateral, widespread action, rotating on their axes, so as to be feathered, or to present their edge, in being drawn forwards, while they offer their flat surface to the water in the backward stroke. The compressed shape of the body of the swimming chelonia, offering so thin a transverse section in passing through the water, contrasts remarkably with the dome-shaped shell of the terrestrial chelonia or tortoises.

The tailed Amphibia (newts) swim, after the manner of the saurians, or ophidia, by simple, lateral, undulatory, strokes of the body or tail. The tailless Amphibia (frogs) swim by the force of their powerful hind-legs, provided with long and webbed toes. The stroke of the frog in swimming is very similar to that of man, and it has often been noted that, in proportion to the size of the body, the frog has a larger muscle of the calf (gastrocnemius), for the extension of its foot upon the leg, than any other animal.

In the previous examples of swimming animals, we have had under observation creatures which, breathing by lungs, and requiring therefore, from time to time, and often at frequent and short intervals, to respire air, cannot be said to inhabit the water, but rather enter it for temporary purposes, for capturing food, or for other ends. They cannot endure continued submergence, except in conditions of hibernation. But we now pass to the contemplation of animals organized for permanent subsistence in, and complete submergence beneath, the water, breathing by gills. Fishes, considered in reference to their manner of swimming, exhibit three principal modes. First, the ordinary mode, by lateral strokes of the body, tail, and caudal fin, in opposite directions, as in common fishes; secondly, by the vertical flapping of the body, lateral fins, and tail, or by vertical undulations of large lateral fins, or of a thin marginal fin, as in the flat fish, torpedo, turbot, sole, plaice, and flounder; and thirdly, by lateral undulatory movements of the body and tail, as in lampreys and eels. Besides this, there are exceptional modes of progression which we cannot notice here.

The first form of progression in Fishes, is the typical one. In the most perfect cases, the body of the fish is elongated, and its centre of gravity, and greatest transverse sectional area of displacement, are situated well forward, the form being suddenly narrowed to the nose, whilst it is gradually narrowed backwards to the tail, a shape which, as has been demonstrated by laborious calculations made in reference to shipbuilding, offers the least possible resistance to progression through water. The body of the fish is deeper vertically than it is thick from side to side, a form which gives it stability in the water, by preventing rolling, and affords more ample space for the attachment of the lateral planes of muscle, destined to deliver the powerful side strokes of the body and tail. There are no vertebræ which can be called cervical, lumbar, or sacral, but all are either dorsal or caudal. There is therefore no neck in the fish, so that the head is fixed directly and stiffly on the trunk, without the intervention of any weak portion or neck. The fins are of two kinds, viz., single and median, and double and laterally symmetrical, fins. The single fins are dorsal, caudal, and post-abdominal or anal; the first and last increase the lateral area of the fish, and add to its balancing power, whilst the caudal fin acts as an extension backwards of the tail, and so increases the power of its stroke. The lateral, double, and symmetrical fins are the right and left *pectoral*, and the right and left *abdominal* or ventral: these are the true *anterior* and *posterior limbs* of the fish; the pectoral pair are always situated at the under and back part of the head, just behind the gill-openings; the abdominal vary in their point of attachment in different species, from a place near or even anterior to the pectorals, backwards to the hinder part of the abdomen. These lateral fins are more used in the slighter balancing, ascending, descending, or turning movements of the fish, than as instruments of progression, that is, in ordinary fishes; for in the ray-tribe they are enormously developed, and form the chief organs of locomotion, whilst by the flying fishes they are employed in flight.

In the ordinary swimming movement, the tail, being first curved slightly forwards to one side, is then suddenly and powerfully extended backwards into the straight position, during which movement it strikes the water obliquely; next passing beyond the middle line, and curving slightly to the opposite side, it again repeats a sharp backward stroke, striking the water obliquely, across the direction of the former stroke, and once more passing the middle line, it repeats the former stroke, and so on in succession, on one side and the other. The reaction of the water takes place, of course, obliquely forwards, in the opposite direction to each backward stroke of the tail, and so tends to urge the centre of gravity of the fish in oblique zigzag lines forward through the water; but in rapid swimming, these two oblique forces are combined into a median resultant force, which impels the fish directly and swiftly forwards. Even then, however, a slight vibrating motion of the head is sometimes visible, the evidence of the double origin of its forward impulse. The question has often been asked, why is it that the resistance of the water to the forward curving of the tail, previous to its making the backward stroke, and in passing beyond the middle line after one backward stroke, previous to its performing another, does not check the movement of the fish forward, by counterbalancing the impulse arising from the backward movements of the tail? The reply to this question appears to be twofold: first, the backward stroke is delivered not only with greater force, but with greater velocity than the forward curving of the tail; and as time is always an element in measuring the effects of force, the backward stroke is superior in practical effect; secondly, the resistance to the forward movement of the fish in the water, is reduced, as we have seen, to the smallest possible amount, first, by the form of the body, and, secondly, by its slipperiness, which prevents friction, whereas to any backward movement of the fish in the water, the edges of the scales, elevated slightly from each other by the curving forwards of the tail, take powerful hold of the surrounding fluid, and so offer great resistance to any sliding backwards of the fish. Whoever has hooked a fish accidentally by the tail, knows how much more difficult it is to lift or drag it through the water, than if it had been caught by its seizing the bait in the ordinary way; a fact which proves the resistance offered by the edges of the scales.

In describing the act of swimming in the fish, we must not omit to mention the existence, in most species, of the air-bladder, or swimming-bladder. This is an elongated receptacle, containing gases secreted by its lining membrane; it varies in form and size, and is situated in the upper part of the abdominal cavity, immediately under the vertebral column; sometimes it is completely closed, but at other times it communicates by a narrow, elongated neck, with the throat, pharynx, or some part of the alimentary canal, of the fish. The air-bladders of fishes will be referred to again in the chapter on Respiration; but, in connection with our present subject, it is obvious that its presence, or absence, and its relative state of distension with gaseous matter, must materially affect the specific gravity or buoyancy of a fish. It is supposed that the fish has some power of regulating the quantity of gas contained within it, and so of adjusting its own specific gravity, to enable it to rise or fall in the water; but no such faculty has been actually proved to exist, and it seems somewhat improbable that the vito-chemical function of such an organ, which is the homologue of the lung, should be subjected directly to the will. It is noticeable also, that the air-bladder appears to be very capriciously distributed amongst the fish tribe, for it is wanting, not only in certain genera amongst certain orders, but also in certain species of a genus, other species of which possess it. Thus there is no air-bladder in the common mackerel, though one species of the same genus (Scomber) possesses it. It is, however, small in fishes which bury themselves in the mud, or live habitually at the bottom of the water; in the common perch, it is closed. Even when fully distended with air, almost to bursting, as I have demonstrated on various dead fish, it fails to render the entire body buoyant in water, for this nevertheless sinks to the bottom. Mechanically considered, it can therefore only reduce the specific gravity in a certain measure, and so economize the muscular effort which is still necessary to enable the fish to ascend in that fluid; whilst the absorption of its gaseous contents will, on the contrary, increase the rapidity of the descent of the fish by its gravity merely. A possible explanation of its use may be, that it serves to render the ordinary attitude of a fish, with its back upwards in the water, more easy to be maintained; for without it, the specific gravity of the upper or dorsal half of a fish is greater than that of the under or abdominal half, owing to the presence of the vertebral column in the former, a difference which would be easily diminished by a minute horizontal column of air placed in the upper half. The adaptability of different fishes for the act of swimming, differs exceedingly according to their form; the swiftest swimmers are those in which the form is rather elongated (herring, salmon, shark); the heterocercal fishes, which have the vertebral column prolonged to the extremity of the upper caudal fin (sharks), are swifter swimmers than the ordinary or homocercal fishes, in which the cleft caudal fin extends beyond the vertebral column. Many fishes swim very rapidly; the salmon is said to travel from twenty to twenty-five miles in an hour. Certain globular forms of fish (diodon, sun-fish) either move sideways slowly, or turn over and over in the water.

Fishes which swim in the third general mode mentioned above, viz., by lateral undulations, effect this object on the same principles as have been already explained in regard to the water-snakes; but they swim submerged instead of on the surface, and invariably have the advantage of the extension of their lateral area by a continuous marginal dorsal and ventral fin. In the flat fishes (sole, turbot), the flapping of the body and the undulatory or wriggling movement of the marginal fins, produce their effect by striking the water obliquely backwards, but in an upward and downward, instead of a horizontal direction; the reaction of the water upon them, takes place therefore along two converging lines, from above and below, instead of from the sides. In the true flat-fish which have no air-bladder (sole, turbot), the flat form of the body is owing to an extension of the neural and hæmal spines, the fish swimming with one side, which is generally white, downwards, and the other, which is brown, upwards. In the skates, rays, and torpedoes, the flat form is owing to the extraordinary development of the anterior or pectoral fins; these spread out horizontally, and are provided with innumerable digits which support the soft parts, and thus form large lateral fins, which, in addition to the tail, are used in swimming.

In the Molluscous animals inhabiting the water, swimming is performed either by the movement of their long arms acting as paddles (cephalopods), or by special little lateral wing-like paddles (pteropods), or by fin-like expansions of the foot, and vertically flattened tail (heteropods), or by aid of the movable respiratory organs or gills (certain marine gasteropods). Of the lamellibranchiate forms, some are fixed, like the oyster, others are attached by a byssus, as the mussel and pinna; some float in the water, and others, like the cockle, jump through the water from the bottom, by aid of their long curved fleshy foot; some bury themselves in sand, whilst others bore into rocks or timber. The free moving Molluscoids mostly float, as the tunicata.

In the Annulose creatures, many, such as the Crustaceans, move by means of the paddle-like action of their numerous limbs, some of these (lobsters and shrimps) also jumping or propelling themselves backwards in the water by rapid flexure of the tail, which for that purpose is fitted with expanded terminal appendages; others of this subkingdom, as the water-beetles, use their limbs as oars (notonecton); others move by the action of multitudes of lateral setæ attached to each successive segment (aphrodite, sea-mouse); others swim by undulatory movements of the body, either by lateral (vermes), or by vertical undulations (leech); others again, in the larval stage of their existence, propel themselves by ejecting water from a receptacle in their body, backwards from their caudal extremity, a movement characterized, from its resemblance to the action of a syringe, as *syringograde*. Of the swimming Annuloids, in certain echinodermata, the swimming motion is sometimes *pinnigrade*, or performed by movable pinnate arms, as in the crinoidea; the rotiferous animalcules move in the water by means of their cilia; the marine worm-like scolecida move by an undulatory action of their bodies.

In the free moving Cœlenterata, one form of movement in the water, often named *pulmograde*, is performed by rhythmical contractions, which occur once in about eighteen seconds, of the entire umbrella-like disc of the animal (Medusæ), and which might be compared to the pulsations of the heart, or to the respiratory movements; other species simply float in the water by means of hollow air-floats or vesicles (Physalia, Portuguese man-of-war), a method of progression called *physograde;* or they have a *syringograde* mode of progression; or, lastly, they move by means of rows of very large *ciliograde*, as in Beroe, Cydipus.

The ciliograde mode of progression is also invariably employed in the swimming acts of the Protozoa, as in the infusoria, and in the gemmæ of sponges.

Locomotion of Man in Air.

This is impossible, except as the result of impulses obtained from solid supports, combined with the effects of gravity. The extraordinary agile, graceful, easy and perfect acrobatic movements of the celebrated Leotard are thus performed, and surpass in elegance the similarly executed movements of the spider, monkey, and of other arboreal and so-called flying mammalia.

Locomotion of Animals in the Air.

Flight, in its highest perfection, is a movement limited amongst the Vertebrata to Birds, and in the Annulosa to Insects. Amongst the Mammalia, however, the comparatively feebly flying bats are found. Certain examples are also seen, as in the flying lemurs and squirrels, of a parachute mode of descent in the air, which cannot be called flight, for such animals are unable to ascend, or even to move horizontally in that medium; the source of movement in them is their gravity, the direction of the action of which is altered by the membranous expansions passing from one limb to the other, which are stretched by the spreading out of their fore and hind limbs. In the bats there is a true power of flight, but it is imperfect in comparison with that of birds, being short in its duration, low in reference to the earth, irregular and fluttering in its character, and incapable of being performed in very gusty weather, or in rain, which drenches the hair and wings of the animal, and so impedes its movement: bats chiefly inhabit temperate climes, and limit their appearance on the wing to serene evenings and nights. The sternum of the bat is proportionately large, and developed downwards into a slight keel for the attachment of a pectoral muscle, which is larger in comparison with the body, than in any other Mammalia; their clavicles and scapulæ are strong, to afford resistance to the drawing inwards of the shoulders in flight; the arm and fore-arm are elongated, and so especially are the metacarpal bones and phalanges of the three outer fingers, between which the web-like expansion of the wings is stretched. This web always extends the whole length of the trunk, backwards to the short, hinder limb, excluding the foot; and sometimes it is continued on to an elongated coccyx or tail, which is used as an effective rudder. The foot, free from the web, is used for prehensile purposes, the bat hanging with its head downwards, and even sleeping, and in cold climates hibernating, in that position. In the fore-limb or hand the thumb is also free, and hooked as a prehensile instrument. The pectoral and other muscles of the fore-limb are very largely developed.

Passing over Birds to Reptiles, we have to select as examples of true, though probably of awkward flight, the extraordinary extinct flying reptiles (pterodactyles, &c.), the formation of the sternum and upper limbs of which sufficiently indicates the manner in which they were used, but leads to the inference that their flight was probably merely an occasional mode of progression, sustainable for short intervals only. Amongst the living reptiles, the little so-called flying lizard or dragon, affords an example of the parachute mode of progression; its lateral membranous expansions are supported by bony processes belonging to the lumbar vertebræ, sometimes named false ribs, but placed altogether behind the proper thorax; these membranes are capable of being shut up, owing to the movableness of the bony processes which support them; and they are extended by special muscles which draw those processes forwards. In the flying Fishes, the so-called flight is accompanied by an impetus taken from the water by the agency of the tail, and of the long powerful pectoral fins, which latter are then spread out in the air, so as to look like wings; but they have only very feeble muscles at their base, and they merely perform a parachute action, and so sustain the animal for a distance of many feet in the air before its gravity again accomplishes its descent into the water. Flying-fish have been known to rise fifteen or twenty feet from the surface of the water, but the usual height is not more than three feet; they may remain suspended in the air about half a minute, and thus pass through a distance of even 300 feet.

In Insects, the mode of flight is explicable on similar principles to those which regulate it in Birds; but here, also, as was mentioned in comparing the locomotion on land, of the Annulosa with that of the Vertebrata, the muscular or moving apparatus is placed within the passive levers on which it acts, instead of outside them. The wings of insects are variously constructed, and present various sizes and forms; they are horny and membranous, in the beetles; soft, and feathered with microscopic scales, in the moths and butterflies; thin and glassy-looking, in the flies and dragon-flies; short, in the earwigs and house-flies; long and narrow, in bees and wasps; broad and full, in butterflies; and enormously elongated in the dragon-flies. Sometimes they are only two in number (diptera); sometimes the anterior ones are converted into protective cases or elytra (beetles); but more commonly they are four in number. These wings, however different in character, are invariably attached to the sides of the thoracic segments, above the proper limbs or legs; they are moved by powerful muscles lying inside the thorax, that part of the body of an insect being developed proportionally to its powers of flight. The base of the stiff framework of each wing projects into the interior of the thorax by a sort of process or spur; and the muscles act upon this spur, those which draw it downwards raising the wing, and the far more powerful ones, which draw the spur upwards, acting in the downward stroke; so that the muscular force is applied in the opposite direction to that in which it acts in the bird or bat. The rapidity, duration, and character of the movement performed by different insects on the wing, depend on the area of their wings, on the number of strokes made in a second, and on the character of those strokes, whether rapid and continuous, as in the dragon-fly, or slower, and more interrupted and fluttering, as in the butterfly. Insects, considering their size, fly with much greater rapidity than birds; the dragon-fly, for example, flies more rapidly than the swallow; this insect has also much greater control over its organs of flight, and can execute a greater variety of movements in the air, even than the most agile bird.

In the Amphibia, amongst the Vertebrata, and in the Mollusca, Molluscoida, Annuloida, Cœlenterata, and Protozoa, there are no examples of flying species.

The organization of birds is entirely, and in every part, directly adapted to flight. First, their biped position in standing and walking, leaves the upper limbs entirely free for locomotion in the air. In the standing posture, the body of the bird is generally raised forward to bring the centre of gravity over the feet, excepting in many swimming birds, as the duck, and others. In flight, the body is usually held more horizontally, and the centre of gravity lies very far forward, a position favorable to that mode of locomotion. In walking, the axis of motion is placed far back, at the hip-joints, but in flight, forward, through the shoulders; and this change in the seat of motion, requires different compensatory changes in the position of the body. The length and free motion of the neck, also render the adjustability of the centre of gravity in flight much more easy. The concentration of weight forward in the trunk is accomplished by the muscular masses being chiefly situated there; the limbs contain the tendons only. The absolute weight of the animal is also diminished as much as possible, in regard to its size and strength, by various conditions, such as the extreme lightness of construction of its skeleton and feathers, the expansion of their solid matter, and the presence of air in the bones and quills. The large size of the lungs in birds, the presence of air-cavities in the body, and even in the bones, the rapidity and energy of their respiratory movements, their consequent high temperature, and the rarefaction of the contained air, are associated circumstances which have been supposed to result in an important diminution of the specific gravity of the animal; but the difference in weight between air at the ordinary temperature, and at 108°, that of the hottest bird, is insignificant, in proportion to the weight of the entire mass of the bird. The chief relation between the energetic respiration of birds, and their adaptation to flight, consists in the provision, through the former, for the rapid decomposition and oxidation of the large muscles engaged in that movement; and also in its endowing the muscular fibre with an unwonted degree of contractility. It is supposed that the air-cavities which occupy spaces between the abdominal viscera, may assist respiration during flight, when the sternum and ribs require to be comparatively fixed, and cannot be used in the respiratory movements, which must then be performed chiefly by the action of the abdominal muscles.

The dorsal and lumbar regions of the spine, in birds, are strong, and comparatively immovable, so that the trunk forms a firm basis for the support of the vibration of the wings; the consolidation of the trunk being, as a rule, proportioned to the powers of flight. The head is usually tapering, so as to offer slight resistance to the air; the neck is long, and can be extended or drawn back, so as, amongst other purposes, to shift the position of the centre of gravity in flight. Moreover, the length of the neck, and the conformation of the jaws, convert the head into a prehensile organ; and as the feet are organized for standing, walking, perching, climbing, or swimming, or for prehensile purposes, the wings are left free to be specially organized for aerial locomotion. Turning to the special contrivances in these parts, we find, first, a double bony arch between the shoulders,—the one, posterior, formed by the coracoid bones, resting on the sternum, and articulating with the scapula; and the other, anterior, formed by the merry-thought, or furcular bone, consisting of the two clavicles united together in front. This compound arch gives stability to the shoulder-joint, by resisting inward thrust. Secondly, must be noticed, the vast surfaces of the sternum, which reaches backwards, sometimes as far as to the pubes, with its deep projecting keel for the attachment of the large, and the two smaller, pectoral muscles, which, often weighing as much as all the other muscles of the body, serve powerfully to depress, and more gently to elevate, and slightly rotate the wings. Other remarkable points of structure are the length of the humerus, radius, and ulma, the simplicity and solidity of the tarsus, and the degradation of the phalanges to a few flat supporting bones for the attachment of feathers. As regards the joints, their movements are specially limited, those of the elbow and tarsus performing simple hinge-like movements; the latter joint being limited to adduction and abduction, so as to have special firmness when extended; and the shoulder-joint moving merely in the directions of extension and flexion, and in the upward and downward direction. The wings present many points of special contrivance; as, for example, the strong attachment of the stiff quill-feathers to the periosteum of the bones of the fore-arm and hand; the curved form, from quill to tip, of these feathers; their peculiar structure, the partial hollowness of their stems, their stiff, horny exterior, and the light pithy character of their contents; the close parallel arrangement and vertical depths of the barbs; the shortness and stiffness of the anterior barbs, as compared with the greater length of the posterior barbs; the secondary barbs, or barbules; the interlocking of the barbules of each feather; the overlapping of the several quill-feathers, the position of which is regulated by multitudes of small muscular slips lying in the skin, there being sometimes four or five slips to each quill-feather; and, lastly, the stiffness of the anterior margin of the wing, as compared with its hinder edge, and the marked concavity of the under surface of the wing, as contrasted with the convexity of its upper surface.

The rarity of the medium in which flight takes place, the slight mechanical resistance it offers, and its feeble sustaining power, dependent on the extreme difference between its specific gravity and that of the bird, necessitate special contrivances, and an enormous relative amount of effort on the part of a flying animal, to sustain or support its weight in the air; but, on the other hand, the resistance to motion through such a medium is so slight, that comparatively little forward impulse is sufficient to propel it through the air. In accordance with these necessities, the wings of the bird operate on the air chiefly in a *vertical* direction; but, be it observed, owing to the more yielding nature of the hinder edge of the wing, the air escapes under that edge, which is lifted up, so that the efficient action of the stroke is not directly downwards, but downwards and a little backwards in the air. The reaction of that medium takes place against the wings in the opposite direction, that is, chiefly upwards, but slightly forwards; and the combined result is to sustain, or lift, the centre of gravity of the body of the bird above the tips of the descending wings, and to urge it also forwards. The former act demands a very large expenditure, but the latter a comparatively small outlay of wing force. The wings, having made their downward stroke, are lifted, and then again descend, and so on. The reasons why the descending stroke of the wing is more effective than the upward movement, are these: first, the holding power of the wing is increased by the concavity of its under surface, and by the concavity of every quill-feather, also by the overlapping of these, and the locking together of their barbs and barbules; whilst in the upward movement, the air passes off the convex surface of the wing and its chief component feathers, and, as it were, filters through, behind the weaker posterior barbs of each feather, and through their unlocked barbules. Secondly, it is probable, that the area of the wing, owing to its more perfect extension, is slightly greater in its downward movement than during its upward movement; a condition also favored by the further yielding and bending of the quills and wings in the upward movement, as compared with their stiffness and diminished curvature in the downward stroke. Lastly, force and time being joint elements in the development of a given momentum, it is probable that the downward stroke is accomplished with greater energy and velocity than the upward movement. Be this as it may, without an extraordinary difference between the efficient action of the downward and the upward movement of the wing, no sustaining, much less a lifting, power would be gained, and the force of gravity would cause the bird to descend to the ground. By rapid strokes of the wings, slightly rotated and firmly held, in a directly downward direction, the bird is lifted upwards perpendicularly in the air. In hovering over one spot, the wings appear to act directly downwards, but probably they are so rotated forwards, as to counteract the effect of the sliding of the air from behind their posterior edges; and thus they merely support the bird at one spot in the air. Progressive movement requires in addition, a slightly oblique force exercised, as just described, downwards and a little backwards, so as to produce a reactionary force of the air upwards and a little forwards. The effect of gravity alone, when once the bird is raised sufficiently high in the air, will produce, owing to the easier escape of the air behind the weak edge of the wings, a forward but gradually descending movement, which is known as sailing through the air. In gliding or skimming obliquely downwards through the air, some birds use their wings outstretched, after the manner of a parachute, whilst others alternate the flying and the parachute movement; some fly continuously, others by jerks, rising by rapid movements of the wings, and falling when these are quiet. The tail operates, in regulating or checking the descent of the bird, obliquely, by gravity. It is also employed as a rudder by which to steer the bird, or to cause it, during active flight, to ascend or descend in the air; when the tail is bent downward, the resistance of the air beneath and in front of it, causes the head of the bird to ascend; when it is raised, on the same principle, the bird is made to descend. The direction of the flight, to one side or the other, is said by some to be caused by the more rapid vibration, and perhaps by the changed position of the opposite wing, rather than, as supposed by others, by any lateral action of the tail. Some birds, especially sea-birds, have a remarkable power of flying, or gliding, on their sides in the air, or of turning completely over; tumbler-pigeons make summersaults over and over again. The protrusion, or retraction, the elevation, or depression, or the lateral movement of the head and neck, which will shift the centre of gravity in corresponding directions, must also aid in determining the direction of flight.

The flight of some birds is very rapid, reaching, it is said, to ninety miles an hour, in the Eider duck, and even to one hundred and one hundred and fifty miles an hour, in the case of certain hawks and falcons. The wings, the characteristic locomotive organs of birds, are sometimes, as in the penguins and auks, modified by being shortened and provided only with short, stiff, closed feathers, so as to act like fins, or paddles, especially in the movements of diving and swimming beneath the surface. In the cursorial or running birds, such as the cassowary, ostrich, and apteryx, the sternum is short, and its keel absent; the clavicles are small, attached firmly to the scapulæ by bone, but do not reach each other in front; the clavicles are even sometimes absent; in these birds, the wing is small, or so rudimentary as to be wholly unlike a wing.

Prehension and Manipulation in Man.

By far the most complicated prehensile instrument in animal mechanics, is the human upper limb; and the singular perfection of all its parts, and especially of its terminal segment, the hand, makes it the most perfect manipulative organ with which we are acquainted, and well fitted for the execution of the various designs and behests of human ingenuity and will. The negative qualities of the human upper limb, considered as a locomotive organ, constitute positive adaptations for its prehensile and manipulative purposes. Amongst these, may be mentioned the following: its smaller size, as compared with the lower limb; the sole bony attachment between the inner end of the clavicle, and the sternum, so slight in comparison with the solid connection of the pelvic bones with each other, and with the vertebral column; the consequent extreme mobility of the scapula and clavicle upon the trunk, as contrasted with the immovability of the pelvis; the shallow socket of the shoulder-joint, and the almost unlimited character of free play of its movements, as contrasted with the deep hip-joint, and its more restrained motions; the complex nature of the elbow-joint, and especially the separate movements of the radius upon the ulna, for the pronation and supination of the hand, as contrasted with the fixity of the tibia and fibula; the lightness of the carpal bones, Fig. 53, 1 to 8, as contrasted with the large size of those of the tarsus (compare Figs. 51 and 53); the articulation of the hand in a line with the forearm, instead of at right angles, like that of the foot upon the leg; the greater length of the metacarpus, Fig. 53, 9, in relation to the carpus, as contrasted with the more equal length of the tarsus and metatarsus, Fig. 51; the standing out of the first metacarpal bone from the rest, Fig. 53, so as to support the opposable thumb; the great relative length of the phalanges of the fingers, 10, 11, 12,—those of the middle finger being about equal in length to the carpus and metacarpus together, whilst, in the foot, the phalanges are not longer than the metatarsus only;—and lastly, the superaddition of particular muscles, not represented in the lower limb, as for example the pronators and supinators of the forearm, and certain special muscles, viz., the long extensors, and the opponens, belonging to the thumb, and the proper long extensors of the fore and little fingers. The great toe, however, is also well supplied with muscles, and possesses, in certain races, a slight prehensile power.

The following details in the structure of the upper limb, require also to be mentioned. The shallow socket on the outer angle of the scapula, called the glenoid fossa, looks neither directly forwards nor outwards, but outwards and forwards. In this socket, the articular surface of the head of the humerus, which forms only $\frac{1}{3}$ of a spheroid, instead of $\frac{2}{3}$, as in the case of the femur, moves freely in all directions on the

Fig. 53.

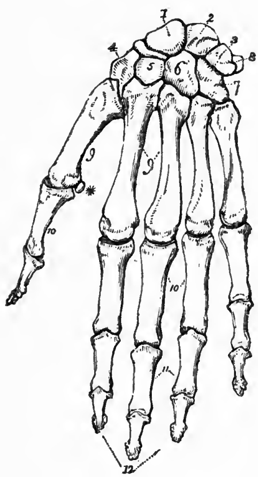


Fig. 54.

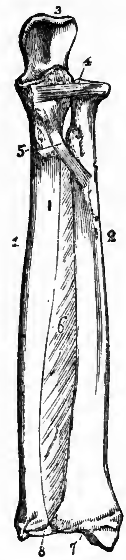


Fig. 53. Dorsal or back view of the bones of the left hand, showing the smallness of the carpus, the lightness and length of the phalanges, the distinct position and length of the thumb. 1 to 8, carpal bones, viz.: 1, scaphoid; 2, semilunar; 3, cuneiform; 4, trapezium; 5, trapezoid; 6, os magnum; 7, unciform; 8, pisiform; 9, 9, the five metacarpal bones, that of the thumb standing out from the rest; 10, 10, first phalanges; 11, second ditto; 12, last or ungual phalanges; *, sesamoid bones of thumb.

Fig. 54. The radius and ulna of the left forearm, seen in front, tied together by their ligaments, to show the mechanism of the joints concerned in pronation and supination. 1, the ulna; 2, the radius; 3, the olecranon process, below which is the great sigmoid notch for the reception of the trochlear surface on the lower end of the humerus; 4, the orbicular ligament, which springs from the ulna, and embraces the head of the radius, without being attached to that bone; 5, the oblique or check ligament; 6, the interosseous membrane; 7, the broad lower end of the radius, with which the hand is chiefly connected; 8, the inter-articular fibro-cartilage which passes from the edge of the lower end of the radius, to the styloid process at the lower end of the ulna, without being attached to the lower articular end of the latter bone.

scapula; but the joint is protected by the tendons of many muscles, and is, moreover, overhung by one process of the scapula, above, named the acromion process, and by another, the coracoid process, in front. The elbow-joint (page 157) presents, on its inner side, a trochlear or pulley-like surface, on the lower end of the humerus, which is received into a deep notch (the greater sigmoid), Fig. 54, found on the front of the olecranon process, 3, at the upper end of the ulna; the two bones are thus so securely fitted, that the ulna moves upon the humerus, in the direction of flexion and extension only. At the outer side of the elbow-joint, the lower end of the humerus is provided with a rounded eminence, continuous with the trochlear surface just mentioned, and having the upper end of the radius, 2, which is slightly hollowed, fitted to it. The inner side of the head of the radius, also smooth and articular, and therefore covered with cartilage, is received into a small notch (smaller sigmoid) on the outer side of the ulna, and a strong collar-like ligament, named orbicular, 4, passes from both borders of this sigmoid notch, and embraces the head of the radius, without being fixed to it. Hence, although, at the elbow-joint, the radius is carried to and fro with the ulna, upon the humerus, in the movements of flexion and extension of the forearm upon the arm, yet, provision is made in the mode of articulation of the radius and ulna at their upper ends, for that peculiar motion between the two bones, which constitutes pronation and supination of the forearm and hand.

A line drawn through the elbow-joint, from side to side, is oblique, the inner condyle of the humerus being longer than the outer one; in consequence of this, when the joint is flexed, the forearm is not bent directly upon the arm, but is carried to its inner side, that is, a little over the body; a similar inclination inwards of the hand, when it bends at the wrist, carries it also still further in front of the body, and hence the hand is brought, by the mere mechanism of the articular surfaces, into a position of constant utility and advantage. At its lower end, the radius is widened out, Fig. 54, 7, and rolls upon the ulna, the two bones being tied together by a strong fibro-cartilage, 8, which passes from the inner border of the radius and neighboring ligaments, below the articular end of the ulna, to be attached to the styloid process of that bone; a small notch on the side of the radius receives a rounded part of the ulna, the reverse arrangement to that which takes place at the upper ends of the bones, where the radius is received into the ulna. The hand is principally connected with the lower end of the radius, the lower articular surface of the ulna being excluded by the fibro-cartilage just mentioned; hence, the hand moves with the radius, and when that bone is rolled upon its axis, supported on the ulna, the hand moves with it, the rolling motion inwards, in which the palm of the hand is turned downwards, being called *pronation*, from the word prone (lying on the face); whilst the rolling motion outwards, in which the palm of the hand is turned upwards and its back downwards, is called *supination*, from supine (lying on the back).

This most admirable arrangement multiplies the use of the hand, enabling it, by this simple additional movement, to operate upwards or downwards, or at any intermediate point. The general motion at the wrist-joint is of a hinge-like character, but slight lateral movements increase the flexibility of the joint in those directions, and this is also augmented, in the direction of flexion, by the arrangement of the carpal bones into two rows. The hand itself is slightly arched transversely in the palm, like the foot in the sole, but scarcely so from before backwards; the concavity of the palm is not intended to give it strength as an organ of support, but besides affording protection to important bloodvessels and nerves, it serves to adapt the hand for holding purposes; moreover, the ends of the metacarpal bones on which the fingers are supported, when looked at endways, are seen to form a curved line, in consequence of which the fingers, when closed, are thrown together, pointing towards the middle of the palm, and are more easily opposed to the thumb. The joints at the base of the fingers, being ball and socket joints, those digits may be spread out laterally, and each may be moved upon its base, in any given direction; whilst the succeeding two joints, being hinge-joints, a certain definition and greater firmness are imparted to the movements of the phalanges themselves. Whilst each finger at its base, and at the last joint, can be bent ordinarily only to a right angle, the intervening or second phalangeal articulation can be bent to an acute angle, an arrangement favored by the splitting of the extensor tendon over the back of that joint; this arrangement evidently permits of a more perfect grasp. The separation of the first metacarpal bone, which supports the thumb, from the rest, instead of being parallel, as in the foot, and the opposability of that digit to the other fingers, have already been mentioned; the joint at the base of that metacarpal bone, next to the wrist, instead of being a gliding joint like the others, is a modified ball and socket joint, capable of movement in all directions; the two remaining joints of the thumb are, however, hinge-joints.

The great distinguishing characteristic of the human hand, as compared with the hand of the so-called Quadrumana, is, besides the better proportion of the fingers, the relative length and perfection of its thumb, which, when the hand is extended, reaches a little beyond the middle of the first phalanx of the fore-finger; whereas, in no anthropoid ape, does it even reach beyond the base of that finger. It was formerly supposed that the presence of two extensor tendons in the fore and little fingers, was a peculiarity especially human; but a double extensor tendon is common in the fingers or toes of quadrupeds, even though only the middle digit remains developed.

It is necessary to add, that by the combination of length with strength, and by the more refined character of the tactile endowment of its broad pulps supported by its expanded nails, as well as by its general mechanism and movements, the human hand is likewise distinguished from the hands of the anthropoid apes and the monkeys.

Prehension and Manipulation in Animals.

As just implied, the hand, in the anthropoid apes, is characterized by the length of the fingers, and the shortness of the thumb. That of the gorilla exceeds in size and power the human member; the shortness of the free portion of the fingers, owing to the extension forwards upon them of the skin of the palm, together with the shortness of the thumb, are characteristics which, though they may increase its mere grasping power, detract from it, in comparison with the human hand, as an instrument for varied work. The length of the entire limb, and that of the muscles also, are further sources of strength in these animals; the latissimus dorsi muscle is attached to the olecranon process, or elbow, which is never the case in man (Fig. 5, 3). In the anthropoid apes, the chimpanzee, the ourang, and the gibbon, the fingers are proportionally longer, and the thumb shorter and weaker. In the still lower monkeys, the long and taper fingers, and the diminutive, and often not opposable, thumb, limit the use of the limb to a comparatively feeble grasp, and constitute a practical mutilation of the member. In the spider-monkeys, with their long grasping fingers, the thumb is wanting. In all cases, however, the general formation of the upper limb, in the apes and monkeys, is similar to that in man; but the length of its various segments is such, that it is longer in proportion than the lower limb,—a circumstance which fits it better for partially bearing the weight of the animal in locomotion, but which renders it more awkward and ungainly as a dexterous prehensile, or manipulating organ. It must not be overlooked here, that, in all the apes and monkeys, the foot is also prehensile, or hand-like, in its action, though it is a foot in structure; hence the use of the term Quadrumanous is not anatomically, though it is teleologically, correct. In the lemurs, the hand is distinctly locomotive, as well as simply prehensile; the thumb is here wanting.

Next to the monkeys and lemurs, a prehensile power is manifested in the limbs of the Carnivora, especially in the feline tribe, in which the hinder, as well as the fore-limbs, are both prehensile and locomotive. In the hinder limb, however, the phalanges of the first or inner toe are absent, and the first metatarsal bone is rudimentary. There is a special contrivance in all four limbs of the cat tribe, by which the last phalanx, which is curved, and provided with a bony sheath for the firm attachment of the hooked claw, can be withdrawn, or protruded, at the pleasure of the animal. At the inner side of the last phalanx but one, is a lateral process, or projection, upon which the last phalanx plays; certain elastic ligaments, passing from one to the other, keep the claw habitually retracted, without effort on the part of the animal, and thus out of the way, in ordinary locomotive acts; but the powerful flexor muscles of the last phalanges move the claws forwards, and so protrude them, when the feet are used for prehensile purposes, as in climbing, or in holding prey, or in acts of offence and defence. It is obvious that these retractile claws are, in this way, saved from unnecessary wear, and are not protruded to the inconvenience of the animal in simple locomotion. A certain power of pronation and supination of the fore paw, is permitted in these animals, by a moderate rolling movement of the radius on the ulna; but this is not to be compared with what is found in the apes and monkeys, in which it equals that possessed by man. In the bears, a greater amount of pronation is permitted than in the cats.

The prehensile power of the limbs, in animals lower than the Carnivora, begins to disappear, first from the hinder limb, and then from the fore limb also; the squirrel and the kangaroo have already been mentioned, but with these, and a few other like exceptions, the fore limb comes to be used perhaps as a burrowing, or climbing, member, but more commonly as a locomotive organ of some kind or other; and the prehensile faculty of the animal is exercised either by the lips and jaws, or else, as in the case of the elephant's proboscis, which possesses not less than 40,000 separate interlacing muscular slips, by a special muscular organ provided for that purpose. The tail also, in certain Quadrumana, as in the spider-monkey, which has no thumb in the hand, is a prehensile organ of great length and power. In accordance with the adaptation of the fore limb to purposes of locomotion only, the movements of pronation and supination between the radius and ulna, are absent in the Ruminants, Solipeds, Cetaceans, and others. In the mole, the burrowing power of the fore limb is provided for, by the shortness and width of the humerus, radius, and ulna, by the limitation of the movements at the shoulder and elbow, and by the presence of a curious sickle-shaped bone, situated between the radius and the base of the thumb, which serves to increase the width of the strong hand. In this animal also, the clavicle is strong, is articulated in a peculiar manner, and has a very large subclavius muscle attached to it.

The characters and structure of the prehensile organs in Birds, viz., the bill and jaws, and the feet and claws, do not require special explanation; neither do those of the powerful prehensile jaws and teeth of the dolphins and porpoises, amongst the Cetaceous mammalia; nor of the large Saurian Reptiles; nor of the sharks, and other predaceous Fishes; nor yet the feebler instruments of the soft-skinned Amphibious Animals and the smaller Fishes. The tongue, in the parrots, is large, and acts against the upper jaw, in holding and turning the food; in the honey-feeding humming-birds, the tip of the tongue is filamentous; in the woodpecker, its point is barbed. The tongues of the woodpecker, chameleon, and toad, likewise, afford examples of special contrivances for the prehension of food, each possessing the power of being suddenly protruded and withdrawn again into the mouth. In the woodpecker, the tongue is supported on a hyoid, or lingual bone, which is bifurcated backwards, and extended, by cartilaginous prolongations, along two grooves on the back of the cranium; these prolongations being drawn forward in the grooves, by proper muscles, the tongue is rapidly extended, and is again retracted by other muscles. In the chameleon, the tongue lies in the interior of a fleshy sheath, composed of circular muscular fibres, by the contraction of which, the tongue is extruded from the mouth, from which position it is again withdrawn into its sheath, by a proper retractor muscle. In the toad, there is a partly similar contrivance; but the tongue, in a state of rest, is bent backwards upon itself, and is rapidly unfolded forwards, at the same time that it is protruded from the mouth. The suckers, or organs of attachment, found in the remora and similar fish, by which they attach themselves as parasites to the whale, or other marine animals, are also prehensile in their character; but for purposes of general prehension, fishes must use their very mobile jaws, the fins never acting in that capacity.

In the soft Mollusca, a prehensile apparatus, by which they hold to foreign bodies, or seize their prey, is frequently present, consisting of tentacula, or arms, which surround the opening of the mouth. In the Cephalopods, these attain their greatest development, being strong muscular organs, provided on their inner or holding surface with numerous discoid, cup-like suckers, the centres of which can be retracted, after they are applied to any foreign body, and so bring atmospheric pressure into exercise upon their margins. The tentacula of other Mollusca and Molluscoida, are much smaller and more delicate organs.

In the Annulosa, prehension is also accomplished by appendages connected usually with the anterior segments of the body, and forming either claws, as in the Crustaceans, or the various forms of mandibles, or jaws, seen in those creatures, as well as in the Insects, Spiders, and Myriapods. Even in the softer Worms and Leeches, prehensile power, confined to the mouth, is well provided for by special horny, or calcareous teeth. The prehensile power of the Annuloida is either buccal, as in the Entozoa, or suctional, as in some Echinodermata, or is performed by long arms, as in others.

In the Cœlenterata, prehension is accomplished by means of tentacula, situated around the mouth; sometimes highly numerous, short, and powerful organs, as in the Sea-anemone; sometimes delicate, elongated, and fringed tentacula, as in the Medusæ, Beroe, and Hydra. Most of the Cœlenterata have their tentacula furnished with the stinging organs already elsewhere mentioned.

The Protozoa can scarcely any of them be said to possess prehensile organs.

Expression and Gesture in Man.

The chief seat of expression in the human body, is undoubtedly the face; but, it must be quite understood that no part of the body is exempt from the liability to undergo movements, which are true manifestations or expressions of internal emotions. Thus, the respiratory muscles are also excited to contract in crying, sighing, sobbing, and laughter. The hand is firmly closed, and the foot is stamped on the ground, in rage; the whole frame is erect, and the attitude and gestures are firm, under a spirit of defiance; whilst the knees are bent, and the body droops, under the influence of fear. The teeth, too, are clenched or opened, in passion or in fright, the movements of the jaws necessary to produce this effect, being caused by the muscles of mastication, not by the proper facial muscles. But it is these latter, together with the muscles of the eyeballs, which are chiefly and remarkably dominated by the passions or emotions, or by the voluntary imitation of these, in the case of the actor. The precise mode in which the eyeballs are moved in different directions, will be explained in the chapter on the Senses. As regards the muscles which co-operate to produce any special expression in the face, space does not allow us to particularize them. It is noticeable, however, that they belong to that class of muscles which are attached to bone by one end only, the other end being fixed to the soft parts, that is, to the skin, so as to pull the integuments in various directions, and produce folds contrary to the line of direction of the muscular fibres themselves: thus, the horizontal wrinkles on the forehead, are produced by the contraction of a muscle (frontal portion of occipito-frontalis), the fibres of which pass vertically down to the eyebrows; whilst the folds produced at the outer corner of the eye in strong laughter, are the result of the contraction of the subcutaneous muscle (orbicularis palpebrarum), the fibres of which pass elliptically, around the opening between the eyelids. The muscles of the face are under the control of a special nerve, called the facial nerve, distinct from the one which supplies the muscles of mastication.

Expression and Gesture in Animals.

There can be no doubt that these are more actively manifested in the Anthropoid apes and monkeys, than in any animals lower in the scale; the attitudes, grimaces, and imitative acts of those creatures, nearly, and sometimes painfully, mimic those of man, and the mechanism of their production is similar. In the other Mammalia, the faculty of expression, however, and of facial expression too, is by no means absent; but by various actions, such as stamping, scratching, pawing, or wagging of the tail, by leaping or slinking movements, they manifest distinctly, and systematically, their various emotions: whilst the change of feature in the countenance, for example, of the lion or tiger, or of the horse, exemplifies the possession of facial expressional power. In many mammalia, the eyeballs become prominent during emotion.

Passing from these to the lower vertebrate animals, features properly so called, or at any rate, movable features, consisting of a soft integument acted upon by subjacent bands of muscle, cease to exist. In Birds, these are replaced by the immovable horny bill, and by feathers which conceal all parts of the head, with the exception of the eyelids and eyes; the feathers of the head and neck, and those around the ear, are capable of being raised under excitement. In the hard-skinned Reptiles, as in the snakes, there are not even eyelids, the common horny integument passing like a fixed watch-glass, in front of the eye, whilst even in the saurian and chelonian group, the eyelid is the only movable feature. The same is the case even in the softer-skinned Amphibia. In the Fishes, the features are still more simple, the surface of the face being little more than a reproduction of the forms of the skeleton beneath, with a few muscles moving the upper and lower lips. In all these cases, from the Bird downwards to the Fishes, we miss, if not the movable cartilaginous eyelids, at least the variously formed cartilage-supported ears, the cartilaginous and movable nose, the fleshy lips, and the soft and movable cheeks: and accordingly, facial expression, reduced in its resources, becomes more and more feeble, or fixed, as we descend in the scale.

To the naturalist, instances of actions and motions, which may be interpreted as belonging to the category of expressional movements, will readily recur in the case of the Molluscous Annulose, and even lower animals. We allude to such movements as the retraction of the tentacles of an alarmed cuttle-fish or sea-anemone, the defiant attitudes of many insects when annoyed, and the rolling up of the oniscus or woodlouse, and other insects, or of spiders, on the approach or contact of foreign bodies, movements apparently intended to imitate death; but these, and other like movements, are instinctive acts, destitute of that element of internal perception or self-feeling which prevails in true emotional or volitional acts of expression.

In man, and in certain animals, there is one mode of expression which is so peculiar and important, that it requires to be considered apart, viz., the production of vocal sounds as exponents of the feelings, emotions, and desires. Speech is a further prerogative of man.

VOICE AND SPEECH.

The Organ of Voice.

The special organ of voice in man, is that portion of the air-passages called the *larynx*, a sort of hollow chamber, which extends from near the root of the tongue to the first ring of the trachea.

The larynx, Fig. 9, *l*, is placed in the middle line of the neck, where it forms a considerable projection, larger above than below; it is suspended from the hyoid bone, *h*, by muscles and ligaments; its cavity communicates with the pharynx, *p*, above, and with the trachea, *b*, below. Although the larynx is the proper organ of voice, yet the lungs and the movable and moving parts of the thorax, serve to propel the necessary air through this organ; whilst the air-passages and cavities above it, including the pharynx, mouth, and nasal cavities, assist in modifying the vocal sounds, and are therefore adjuvant and supplementary organs of voice.

The framework of the larynx is made up of cartilages, which are connected together by ligaments, and furnished with muscles, extrinsic and intrinsic; the whole organ is of course supplied with bloodvessels, nerves, and lymphatics; its interior is lined by a highly sensitive mucous membrane.

The *cartilages*, which constitute the basis of the organ, are four in number; viz., the cricoid, thyroid, and the two arytenoid. The *cricoid*, Fig. 55, *a*, *b*, 5, Fig. 56, B, 5, which resembles a signet-ring placed vertically, with its broader portion turned backwards, forms the base or lower part of the organ. On the summit of the posterior border of the cricoid, are the two *arytenoid* cartilages, one on each side, Figs. 55, 56 *; these are two small pyramidal pieces situated close to each other, and connected with the cricoid cartilage by means of true ball and socket joints. Each presents at its base, an anterior and a lateral process. As we shall hereafter see, they are most important structures in the production of the voice. The *thyroid* cartilage, 2, 2, rests upon the fore part of the cricoid; it is the largest cartilage in the larynx, covering the others in front and at the sides. It consists of a broad, cartilaginous plate, forming two wings or alæ, united at an acute angle in the middle line in front, where it forms the projection called the *pomum Adami*, or *Adam's apple*, Fig. 9; its right and left hinder borders terminate, above and below, in little processes; of these, the two upper ones, called the *superior cornua*, serve to connect the cartilage, by means of ligaments, with the hyoid bone; and the two lower ones, called the *inferior cornua*, present each a small, smooth, oval surface for articulation with the cricoid cartilage. The cartilages of the larynx are composed of pure cartilage; in advanced age, they frequently undergo partial ossification.

Behind the tongue, and in front of the upper opening of the larynx, is a curved, upright, fibro-cartilaginous plate, named the *epiglottis*,

Fig. 9, *e*, Figs. 55, 56, 1; it is leaf-like in shape, and acts as a safety-valve, preventing the intrusion of any foreign bodies into the larynx during the act of swallowing.

Fig. 55.

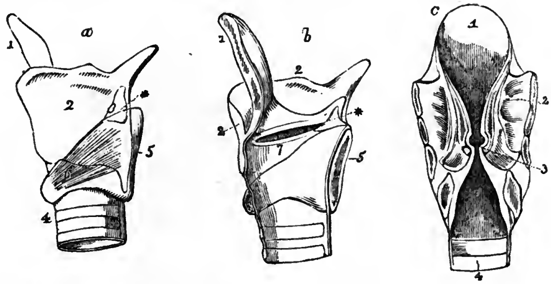


Fig. 55. Three views of the dissected human larynx. *a*, left side of the larynx, showing the cartilages; 1, the epiglottis; 2, the thyroid cartilage, its left ala or wing; 4, upper rings of the trachea or windpipe; 5, the cricoid cartilage; 6, the left crico-thyroid muscle; *, the position of the left arytenoid cartilage, shown by a faint outline; *b*, the inner side of the right half of the larynx, which is supposed to have been divided longitudinally down the middle line; 1, section of epiglottis; 2, 2, right half or ala of the thyroid cartilage; 5, ditto of cricoid; 7, right true vocal cord; above this, is the long opening of the ventricle of the larynx, above that, the false vocal cord; *c*, perpendicular section across the larynx, showing the posterior surface of the anterior half of the organ; 1, hinder surface of the epiglottis; 2, section of the right half of the thyroid cartilage; 3, section across both the vocal cords, and the intermediate chink, or glottis, with the ventricles of the larynx above them; 4, anterior part of the trachea.

The inferior or tracheal opening of the larynx is small, and roundish; but the superior or pharyngeal opening, Fig. 56, is larger, and triangular in form, being wide in front and narrow behind. It is bounded on the sides by two folds of mucous membrane, which pass from the arytenoid cartilages * forwards, to the side of the epiglottis, 1, which may be said to form its anterior boundary. On looking down through this opening, two folds of the lining membrane are seen passing from the arytenoid cartilages behind, to the receding angle of the thyroid cartilage in front: these are the *superior* or *false vocal cords*, so named because they are not concerned in the production of the voice. Below these, and extending from the small process or projection on the fore part of the arytenoid cartilage, to the recessed part of the thyroid cartilage, are the *true vocal cords*, Figs. 55, 56, 7, the essential organs of voice; they are made up chiefly of yellow elastic tissue, covered by mucous membrane; and they form two sharp ridges or projections, having very fine and smooth edges, turned towards each other, and placed accurately on the same level. Between the true vocal cords, Fig. 56, is a narrow, somewhat triangular interval or fissure, wider behind than in front, called the *glottis*, or *rima glottidis* or *chink of the glottis;* in man, it is about eleven lines in length, and nearly half an inch in width at its widest part; its measurements in the female, are two or three lines less; at its hinder part, or base, the triangular fissure is bounded by the arytenoid cartilages, on either side, for the vocal cords do not extend so far back. This hinder part of the fissure is called the arytenoid portion. Above each true vocal cord is a cavity on either side, named the *ventricle of the larynx*, Fig.

55; this leads, anteriorly, into a pouch of the mucous membrane called the *laryngeal sac*, the surface of which is scattered over with sixty or seventy mucous glands, the secretion from which serves to maintain the vocal cords, and surrounding parts, in a moist condition.

A Fig. 56. B

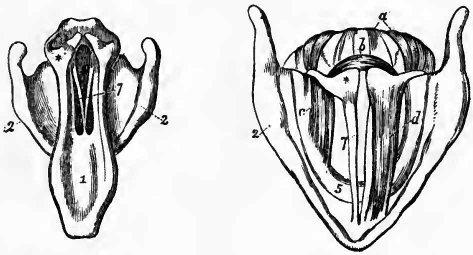


Fig. 56. Two bird's-eye views of the larynx, the back part of the organ being turned towards the top of the page: the left-hand figure, A, has the mucous membrane partly left on; the right-hand and large figure. B, is dissected, to show the muscles and separated vocal cords. In the former figure the epiglottis is marked 1, thyroid 2, 2, the right arytenoid *, and the vocal cords 7; between them is the glottis, or rima glottidis or chink of the glottis; outside them are the ventricles of the larynx. In the left-hand figure, *a* is the posterior crico-arytenoid muscle; *b*, the arytenoid muscle passing across the middle line; *c*, the lateral crico-arytenoid muscle; *d*, the thyro-arytenoid muscle; 7, the right vocal cord. 2, is the thyroid cartilage; 5, the cricoid; *, the right arytenoid.

Connected with the laryngeal cartilages, are several small muscles, which, with one exception, exist in pairs. The *crico-thyroid* muscle, Fig. 55, *a*, 6, extends from the side of the thyroid cartilage to the cricoid cartilage. Arising from the side of the cricoid, and passing upwards and outwards to the lateral process of the base of the arytenoid cartilage, is the small *posterior crico-arytenoid*, Fig. 56, B, *a*. The *lateral crico-arytenoid*, *c*, passes backwards and upwards, from the cricoid to the lateral process of the arytenoid cartilage. On the outer side of each vocal cord, and lying parallel with it, is the *thyro-arytenoid* muscle, *d*, which extends from the recessed angle of the thyroid cartilage, to the base of the corresponding arytenoid cartilage. The *arytenoid*, *b*, is a single muscle connected with the posterior surfaces of the cartilages of that name.

The *mucous membrane* of the larynx is covered in the greater part of its extent with a columnar, ciliated epithelium; but the vocal cords, and the mucous membrane above them, except for a short distance in the middle line anteriorly, are covered with epithelium of the squamous variety. It is continuous above, with the membrane lining the mouth and pharynx, and below, with that of the trachea, and, with the exception of the parts covering the vocal cords, is studded with mucous glands, the secretion of which keeps the surface duly moistened; on the epiglottis these glands are very numerous. Its *nerves* are derived from the superior and inferior laryngeal branches of the pneumogastric, together with filaments from the sympathetic. The inferior laryngeal nerve supplies all the muscles except the crico-thyroid; the superior laryngeal supplies that muscle and the mucous membrane. The arytenoid muscle is said to receive branches from both nerves. A portion of the laryngeal motor fibres of the pneumogastric are derived from the spinal accessory nerve.

The Production and Modification of Sounds.

Whenever a solid body surrounded by air, is thrown into *vibrations*, in any direction, the sensation of *sound* is produced in the ear, provided the vibrations be of a certain strength, and follow each other with a certain rapidity. It is usually stated, that if the vibrations are fewer than 8, or more than 24,000 per second, no effect is produced on the nerve of hearing; but, according to other authorities, fewer than 16 or 32 vibrations per second are inaudible; and vibrations continue to be so which number 32,000, or even 70,000 per second. When the vibrations exceed a certain high number, the distinction between two near sounds is no longer possible; the perception of sound remaining, though not the power of distinguishing them. Bodies vibrate by virtue of the elasticity imparted to them by their molecular structure. The undulations of the air may generate sound, or sound may be communicated to the air by the vibrations of another body. For the production of a musical sound, the vibrations must succeed each other at regular intervals; if the vibrations occur at irregular intervals, only a noise results. The *pitch* of a sound is determined by the number of vibrations in a given space of time, becoming higher in a direct proportion to the rate of rapidity of the vibrations. Its *strength* or *intensity*, depends on the extent of the vibratory action of the sonorous body. The peculiar character of a musical note, whereby it can at once be distinguished from another note of exactly the same pitch and strength, is called its *tone* or *timbre*, and is dependent on the nature and shape of the vibrating body. A sonorous body may vibrate throughout its whole mass, or in separate parts; in the latter case, these parts vibrate in opposite directions, and are separated from each other by stationary points called *nodes* or *nodal points*.

The *stretched cords*, or strings, of stringed instruments are examples of bodies rendered elastic by tension. They emit feeble tones, unless they are connected with some resonant body. When a tense cord is made to vibrate throughout its entire length, it yields its deepest or fundamental note; if the cord be divided into equal parts by a bridge placed under it, the note heard, when it is made to vibrate, is the octave of the fundamental note. Hence the law, that the number of vibrations of any two strings, having the same degree of tension, is, other things being equal, inversely as their length. The number of vibrations is also dependent on the thickness of the strings and their tension, being inversely as the thickness, and proportional to the square root of the tension. During the transverse vibration of a cord in its entire length, other and higher sounds than the fundamental note may be heard, produced by the vibrations of aliquot parts of the cord. These aliquot parts are called the harmonic divisions of the cord.

The vibrations of *elastic rods* resemble those of strings; but the number of vibrations is inversely as the square of the length, and directly as the thickness of the rod.

The musical sounds in simple *wind instruments*, are the result of the successive condensations and rarefactions of the air through a tube. The pitch of the note, when the column of air within a tube is thrown into vibrations, is determined by the length of the tube and the strength of the blast; being lower in a direct ratio with the greater length of the tube, and higher the greater the force of the impulse, for increase in the strength of the blast leads to the formation of nodal points. If the air, in a tube closed at one extremity, be thrown into undulations, the deepest, or fundamental, note is an octave lower than that yielded by a similar tube with an open extremity; in the latter case, a nodal point is formed in the centre of the column of air; whilst in the former, the nodal point is the closed extremity of the tube.

The essential parts which enter into the formation of *tongued instruments* are —first, the *wind-tube*, through which the column of air is driven; secondly, the *tongue*, or vibrating body, which may be rigid or membranous; and lastly, the *attached tube*, placed beyond the tongue.

The arrangement and position of the tongue are such, that, when at rest, but little or no air can pass through from the wind-tube; but when a column of air is driven through the latter, the tongue yields in the direction of the attached tube, and an opening is thus established for the outward passage of the air-current. The rapidity with which the tongue at first yielded to the impulse communicated to it, gradually diminishes, because an opening being now established for the escape of the air, it is less exposed to its action. The tongue, by virtue of its elasticity, now counteracts the force of the impulse, and has a tendency to return to its original position; in so doing, the opening becomes smaller, the backward movement of the tongue momentarily interrupts the escape of the air-current, which, now acting with increased power, again causes the tongue to recede: in this manner, a series of more or less rapid oscillations is produced, which throw the column of air in the attached tube into vibrations. The opinion generally entertained is, that the air itself is, in tongued instruments, the primary source of the sound. It is, however, maintained by some that the sounds result from the vibrations of the tongue itself, and that the impulses communicated by it to the air, merely give increased power to the sound produced by its own vibrations.

The *pitch* of the sound, *i. e.*, the frequency of the vibrations, of an instrument with a *rigid* tongue, when unprovided with an attached tube, is dependent on the elastic strength and length of the tongue. As in the case of elastic rods, the number of vibrations of rigid tongues is inversely as the squares of their length; thus, a tongue six inches long, vibrates four times more rapidly than a tongue, of the same material and equal thickness, twelve inches long. But the pitch of the sound yielded by a rigid tongue, is modified, when an attached tube or body is joined to it; for the vibrations of the tongue and those of the tube, though they may each produce notes differing widely from each other as regards pitch, yet, when they are connected together, their joint vibrations produce only one sound. The pitch of the note of a rigid tongue is lowered, when the force of the blast is increased. The pitch is never raised by the addition of an attached tube; moreover, it is not perceptibly modified, so long as the tube is of a moderate length. Gradual lengthening of the tube, however, lowers the pitch; the rapidity with which this lowering of the pitch takes place, gradually increases with further lengthening of the tube, until, at a certain point, the pitch becomes an octave lower. The tube is now of such a length, that, if air were propelled into it, it would produce the same fundamental note as the tongue without the tube. If the tube be further lengthened, the pitch of the note is, at first, the same as that of the tongue; but still further lengthening of the tube, again lowers the pitch, now, however, only to a fourth; and so on.

The action of *membranous* tongues is, however, of greater immediate interest to the physiologist. These tongues, unlike rigid tongues, which, as already stated, behave in their vibrations as elastic rods, vibrate according to the same general law as stretched strings. If one extremity of a short tube be covered by two portions of elastic membrane, or vulcanized India-rubber, in such a manner as to leave a small chink between them, a form of double membranous tongue is obtained, which, in its action, bears a close resemblance to the vocal cords of Man. Sounds are more easily produced by such a double tongue, the narrower the chink; the size of the latter, however, in no way affects the *pitch*, which is determined by the length, tension, and thickness of the tongues. The pitch of the note is heightened by touching the tongues with a firm body, a nodal point being then formed. If the two tongues have the same degree of tension, the sound emitted is of a deeper pitch than the fundamental note of either tongue. If they are subject to unequal tension, either one tongue alone is thrown into vibrations; or if both vibrate together, two different notes may be produced; or lastly, if they accommodate their vibrations to each other, one sound alone is emitted. The pitch of the notes produced by membranous tongues, either with or without an attached tube, is, moreover, heightened, by increasing the strength of the blast of air; in this respect, membranous tongues differ essentially from rigid tongues, in which the pitch is somewhat lowered, when the force which throws them into vibrations is increased. The pitch of a membranous tongue, combined with an attached tube, undergoes modifications closely resembling those of a rigid tongue with an attached tube. Lengthening of the tube causes the pitch to fall by semitones, but it does not sink a whole octave, as happens with rigid tongues. When a wind-tube is added to a tongue, the effects produced on the pitch, by lengthening it, are similar to those produced by increasing the length of the attached tube. Diminution of the calibre of that part of the wind-tube nearest to the tongue, heightens the pitch of the note. Partial covering of the end of the attached tube, causes a lowering of the pitch.

The Production and Characters of the Human Voice.

The researches and observations of physiologists have long since proved that the sounds of the voice in man and mammalia are produced by the *vibratory action of the vocal cords*, during the passage of the air through the glottis; and that these cords vibrate according to the laws which regulate the vibration of stretched membranous tongues. Experiments on living animals show that the vocal cords are alone the essential organs for the production of voice, for so long as these remain untouched, although all the other parts in the interior of the larynx be destroyed, the animal is able to emit vocal sounds. Diseases of the larynx in man produce similar results. Again, if all the structures of the larynx of a dead animal, except the vocal cords, be removed, and these be rendered tense and approximated, vocal sounds can be generated by forcing currents of air through the glottis from below. If the human larynx be removed from the body, and currents of air be made to pass, from its lower end, through the glottis, sounds are also produced. By making an opening in the larynx of a living animal, so as to expose the vocal cords, the vibrations of these may be distinctly seen during the emission of vocal sounds. The existence of an opening in the larynx of a living animal, or of man, *above* the glottis, in no way prevents the formation of vocal sounds; such an opening, if situated in the trachea, causes total loss of voice, but by simply closing it, vocal sounds can again be produced. Such openings, in man, are met with, either as the results of accidents, of suicidal attempts, or of operations performed on the larynx or trachea, for the relief of disease. Division or injury of the laryngeal nerves, at once destroys voice, the muscles which regulate the tension of the vocal cords being then paralyzed. Lastly, by means of the laryngeal mirror, or *laryngoscope*, of M. Garcia, the vocal cords can be seen to vibrate during vocalization. The laryngoscope consists essentially of a small flat metallic mirror provided with a long handle; being introduced into the pharynx through the open mouth, it is made to receive rays of light from the sun, or from a lamp, thrown upon it by means of another large and concave mirror placed in front of the mouth; the small mirror is held with its surface at such an angle that the rays of light are thrown down from it upon the laryngeal opening, and so illuminate it. But the light reflected back from the larynx on to the small mirror produces on its surface an image of the parts, which image is, of course, again reflected towards the larger mirror. In the centre of the latter is a small aperture, behind which the observer places his eye, and, in this manner, some of the rays are intercepted by the eye, and a laryngeal picture is visible. By means of this instrument, which has been recently introduced into medical and surgical practice for the investigation of laryngeal diseases, the root of the tongue, the epiglottis, the projections formed by the arytenoid cartilages, part or even the whole length of the vocal cords, a part of the tracheal mucous membrane, and sometimes also the bifurcation of the trachea, are seen in form of a reversed picture on the smaller mirror. By observations thus made, it has been determined that, whilst in respiration, the vocal cords are inclined from each other, and the glottis is wide open, in speaking or vocalization the vocal cords are seen to be approximated, and to vibrate. In ordinary tranquil breathing the cords are widely separated, so that the glottis, which is now partly hidden from sight by the epiglottis, has a triangular form; it increases slightly in size at each inspiration, especially when the respirations are hurried and the inspirations deep; during expiration the glottis contracts. Moreover, during vocalization, or the production of pure vocal sounds, the arytenoid cartilages are said to become erect, and almost to touch each other; the posterior portion of the glottis between these cartilages is quickly and completely closed, whilst the anterior two-thirds are open, so as to leave a very fine fissure; this last-named part is therefore named the *vocal* glottis, the hinder part being named the arytenoid or *respiratory* glottis. When the vocal glottis is wider than one-tenth of an inch, no sound is producible. Müller had previously shown, on the dead larynx, that the portion of the glottis between the bases of the arytenoid cartilages is in no way connected with the production of the voice, for vocal sounds can be heard both when the glottis is open in its entire length, and also when its posterior part is closed; in the former case, however, the sounds are weak and difficult of production, though their pitch remains unaltered. Moreover, he found that if the anterior projections of the arytenoid cartilages be brought into contact, so as to leave an opening behind and in front of them, and air be passed through the hinder opening, no second vocal sound could be heard.

The *actions of the muscles*, which, by lengthening or shortening, by tightening or relaxing the vocal cords, or by drawing them together or apart, govern the aperture of the glottis, and so aid in the production of the voice, and modify the pitch of the notes, now require to be briefly examined.

The contraction of the two crico-thyroid muscles, Fig. 55, *a*, 6, right and left, draws the thyroid cartilage, 2, forwards and somewhat downwards upon the cricoid cartilage, 5; or supposing the thyroid cartilages to be fixed, these muscles would draw the cricoid cartilage backwards and upwards from the thyroid. The arytenoid cartilages, *b**, in both cases, on account of their connection with the cricoid, are thus separated from the recessed part of the thyroid cartilage, and hence the vocal cords, 7, are both *lengthened* and rendered more *tense.* When this happens, or supposing that the principal action of the crico-thyroid muscles is to maintain the thyroid cartilage fixed in regard to the cricoid, the innermost bundles of the posterior crico-arytenoid muscles, Fig. 56, B, *a*, draw backwards the arytenoid cartilage, *, and, in this manner, the length and tension of the vocal cords, 7, are still further increased. When the action of the crico-thyroid and posterior crico-arytenoid muscles ceases, the anterior and posterior points of attachment of the vocal cords to the thyroid and arytenoid cartilages, respectively, are drawn nearer to each other by the lateral crico-arytenoid, *c*, and especially by the thyro-arytenoid muscles, *d;* thus the cords are *relaxed*, and they become, by virtue of their elasticity, *shorter.* By some anatomists certain fibres of the thyro-arytenoid muscles are described as entering or mixing with the elastic tissue of the vocal cords; and these muscles are believed by them to be able thus to tighten the cords, even when they become shortened. The lateral crico-arytenoids are, in that case, when acting alone, said merely to shorten the vocal cords, without tightening them. These two muscles may also act together.

The *narrowing* of the glottis is effected by the single arytenoid muscle, Fig. 56, *b*, which, passing across the middle line, draws the arytenoid cartilages, *, together, and, in this manner, approximates the vocal cords, or may even completely *close* the glottis. Besides this, the lateral crico-arytenoid muscles, *c*, also narrow the glottis; for, by their contraction, they draw forward the lateral processes of the arytenoid cartilages, and thus swing inwards their anterior processes, *approximate* the vocal cords, and bring them into a state of *parallelism.*

With regard to the *opening* of the glottis, it may be observed that each arytenoid cartilage is, as we have seen, Fig. 56, furnished with an anterior projection for the attachment of the corresponding vocal cord, 7, and with a lateral process for the insertion of the lateral, *c*, and posterior, *a*, crico-arytenoid muscles; moreover, it is so articulated on the upper surface of the cricoid cartilage, that besides being able to move backwards and forwards, and from side to side, it can also perform a movement of rotation upon its vertical axis, that is to say, upon an imaginary line passing through it from above. Hence, the outer fibres of the posterior crico-arytenoid can pull the lateral processes of the arytenoid cartilages backwards, swing their anterior processes outwards, and, in this manner, *separate* the vocal cords from each other posteriorly, and so *widen* the glottis, especially behind.

When, in tranquil breathing, the glottis is open and triangular, only a soft sound is produced by the passage of the air through its aperture; the vocal cords are at rest, but still in a certain state of tension, and not loose or relaxed; during very rapid and powerful expiration, however, a blowing or panting sound is audible, caused by the friction of the air against the walls of the air-passages. The human vocal apparatus is analogous to a wind instrument with a *double membranous tongue*, the *bronchi and trachea* representing the *wind-tube*, the *vocal cords* the double *membranous tongue*, and the *parts above the glottis* the *attached tube.* For the production of vocal sounds, even the feeblest, more air must pass through the glottis than in respiration; and this current of air must undergo periodic interruptions in its passage through that fissure. The vocal cords, moreover, are made more or less tense, and are approximated, so as to be parallel to each other, and the fissure of the glottis is converted into a fine chink-like opening. The escape of the air propelled upwards through the trachea, being thus retarded, the margins of the vocal cords are forced upwards, and slightly separated from each other; the elasticity of the cords is now called into play, so that they counteract the force of the impulse communicated to them, and, by a downward recoiling movement, again narrow the glottis. In this manner, the oscillations into which the vocal cords are thrown by the escape of the air driven from the trachea, or wind-tube, are communicated to the less tense air above the glottis, and throw this into vibrations. By means of the laryngeal ventricles or sacs, placed above the vocal cords, these latter are kept free, so that their vibrations are easily accomplished. It has also been supposed by some, that the superior vocal cords maintain the strength and quality of the sounds, by entering into simultaneous and synchronous vibrations. This is contrary to Señor Garcia's observations with the laryngoscope; but he found that, in elevation of the pitch of the voice, whether natural or falsetto, the superior vocal cords approach each other, so as to narrow the part of the vocal tube above the glottis.

The human voice, from the lowest male to the highest female voice, has a range of nearly 4 octaves, the lowest note being E,* caused by 80 vibrations per second, and the highest C,† caused by 1024 vibrations in the second. But if extreme cases be included, the range is nearly $5\frac{1}{2}$ octaves, the lowest note being F,‡ caused by 42 vibrations, the highest A,§ by 1708 vibrations (Vierordt). In the same individual, the compass of the voice, in singing, generally extends over 2 octaves; in some rare instances, however, it has been known to include even $3\frac{1}{2}$ octaves. In ordinary speech, the range of the voice is usually about half an octave. The production of these different notes is effected by alterations in the length and tension of the vocal cords, and by changes in the degree of approximation and separation of these; thus, during the emission of the low notes, the cords are longer, looser, and more widely separated from each other, than they are during the production of notes of a higher pitch, and the air passes through the glottis more slowly, but in larger quantity. It has been calculated that 240 different states of tension of the vocal cords must be accurately producible at will, to account for all the notes and intermediate tones possible in a perfect human voice of ordinary range. The celebrated Madame Mara could effect as many as 2000 changes.

There are four different *varieties* of voice, viz., the *bass*, *tenor*, *contralto*, and *soprano*—the two former being characteristic of the male

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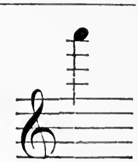
§ 

sex, the two latter of the female; there are besides, two subdivisions known as the *baritone* and *mezzo-soprano*, the baritone being intermediate between the tenor and bass, and the mezzo-soprano intermediate between the soprano and alto. The lowest note of the contralto voice is about an octave higher than the lowest note of the bass voice; and the highest soprano, about an octave higher than the highest tenor. As a rule, the bass voice possesses a lower range than the tenor, and the tenor a higher range than the bass; in the same manner, the contralto extends lower than the soprano, and the soprano higher than the contralto. These varieties of the human voice differ, therefore, in their *pitch;* this is due to the different dimensions of the vocal cords; thus, their length in the male and female, when in a state of tension, is as three to two; and, moreover, their breadth and thickness are greater in the former than in the latter.

Besides differing in pitch, the various kinds of voice differ in their *quality*, *tone*, or *timbre*, and this is a most marked difference; for a bass voice can frequently sing the higher notes of a tenor voice, and the alto the higher notes of a soprano; and yet there is a great and essential difference, in either case, between the notes produced, a difference which must be dependent on peculiarities in the form and structure of the vocal apparatus. The difference in the tone, or timbre, of the *male* and *female voice*, is due to the great difference in the walls of the larynx in the two sexes; in the female, the laryngeal cavity is not so capacious as in the male, the angle formed by it in front is much less acute, and the cartilages themselves are softer. The voice of *boys* is, like that of women, either soprano or alto; it is, however, louder, and possesses a different tone. The larynx presents no difference in the two sexes, until the period of puberty is reached; in boys, this organ then rapidly increases in size, the vocal cords become longer, thicker, and coarser in structure, and the voice, which at first is imperfect, and often hoarse, at length becomes tenor, or bass, finally attaining that deep tone characteristic of man.

The general *strength* of the voice is influenced by the capacity of the chest, the development of the muscles engaged in vocalization, the extent to which the vocal cords can vibrate, and the power of communicating resonance, possessed by the air-passages and neighboring cavities and sinuses. When the loudness or intensity of a vocal sound is increased, the pitch remaining unaltered, the vocal cords undergo a certain degree of relaxation, in order to compensate for the increased strength of the blast, which would otherwise heighten the pitch; this relaxation of the cords is, of course, proportional to the increased force of the air-current. Experiments on the human larynx show that, in this manner, one and the same note can be obtained by a stronger tension and a weaker blast, as by a weaker tension and a stronger blast; these notes, although of the same pitch, differ considerably in tone, being, in the latter case, harsh and disagreeable.

The vocal sounds are further modified by the elevation and depression of the larynx; for when the voice is raised from a low to a high pitch, the whole larynx is elevated towards the base of the skull,

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drawing with it, at the same time, the trachea; but the mode in which the trachea and the attached vocal tube, or parts above the glottis, influence the voice, is not yet determined. The experiments of Müller on the human larynx, show that alterations in the length of the wind-tube and of the attached tube, have but little or no effect on the pitch of the voice; whereas, as already stated, alterations in the length of these tubes modify very considerably the pitch of the notes of artificial, rigid, and membranous tongues. According to this physiologist, the alteration in the length of the attached vocal tube, produced by the ascent and descent of the larynx, is not more than an inch, and does not modify the height of the notes, the increase or diminution in the length of the tube, produced by the depression or elevation of the larynx, merely affording increased facility for the formation of the low or high notes. It is, however, maintained by some, that the total length of the trachea, with the cavities above the glottis, is in reality shortened by the ascent of the larynx, the trachea rising out of the thorax, almost as much as the larynx ascends; but, considering that the actual alteration in length is so slight as not to account for the changes in the pitch of voice, they are of opinion that a diminution in the diameter of the trachea, produced by the upward movement of the larynx, together with variations in the tension of its walls, enables it to accommodate itself to the different vocal tones. (Wheatstone and Bishop.) The trachea may, in being drawn upwards, be narrowed by about one-third of its diameter.

In the production of the higher notes of the voice, the thyro-arytenoid muscles take an active part. As already stated, the pitch of the note of a membranous tongue is heightened when the calibre of that part of the wind-tube nearest to the tongue is lessened. The thyro-arytenoid muscles, by narrowing the diameter of the larynx, just below the vocal cords, influence the voice in a similar manner. It was found by Müller, that on removing these muscles from the human larynx, and imitating their action, by pressing inwards the thyroid cartilage on each side, below the vocal cords, higher notes were produced. During the ascent of the voice, the soft palate is depressed, and the tonsils are approximated. The epiglottis, when depressed, is supposed to influence the pitch of the voice, causing the notes to become graver and duller, for partial covering of the end of the attached tube of a wind instrument, as already mentioned, causes a lowering of the pitch.

The peculiar tone of the voice in different persons, or the *personal quality* of the voice, is due to the form of the air-passages generally, to the condition of the mucous membrane, and to the power of resonance of those cavities: the peculiar quality of the voice, known as the *nasal* tone, is due to similar causes. If the nostrils be closed, the natural tone of the voice is not affected, so long as the arches of the palate do not approach each other; when, however, they are approximated, the nasal tone is produced; the larynx, at the same time, ascends much higher than in the production of the natural tones. The nasal tone can also be produced, when the external apertures of the nares are open, whether the mouth be closed or not; the larynx is then elevated, the palatine arches undergo contraction, the dorsum of the tongue ascends towards the palate, and the air escapes between the contracted palatal arches, the resonance of the nasal cavities alone being communicated to it. Another variety of voice, called the *veiled* tone, is produced by lowering the larynx, so that this is covered by the entire pharynx, whilst the base of the tongue is approximated to the palate, and the voice resounds in the upper part of the pharynx, beneath the skull. The resonance of the voice is also influenced by the relative capacity and elasticity of the thoracic walls, all parts of which, especially, however, the sternum, act as resonant organs, as well as the pharynx, mouth, nasal cavities, and even the cranial sinuses and bones.

In both sexes, but especially in the male, two series of notes, differing both in pitch and quality, can be produced, viz., the notes of the *natural* voice, called the *chest* or *true* notes, and the *head* or *falsetto* notes. The former are fuller, stronger, and more resonant; the falsetto notes, on the other hand, are softer, less clear, have somewhat of a humming sound, and resemble slightly the harmonic notes of strings. The lower notes of the voice are chest notes; the higher notes are falsetto; the middle notes of the scale can be produced alike by the chest or head voice. The transition from the chest to the head notes takes place, in some voices, imperceptibly; in others, the change is well marked.

Various theories have been put forward to explain the manner in which the falsetto voice is produced. By Müller, the real cause of the difference between the chest and falsetto notes was thought to be that, for the production of the former, the whole breadth of the vocal cords vibrated; whereas, for that of the latter, only their thin inner margins, or borders, are thrown into action. Another theory was, that the falsetto notes are produced, whilst the glottis is partially closed, by the vibrations of only one-half of the length of the vocal cords. (Mayo and Magendie.) The falsetto notes have also been supposed to be produced by the vibration of the cords in segments, separated by nodal points, so that harmonics of the fundamental notes are formed. (G. Weber.) It has been thought by some that the vocal cords do not take any part in the formation of the falsetto notes, but that these are produced by the vibration of the air itself, in its passage through the glottis, acting like the blow-hole of a flute. (Pétrequin and Diday.) Lastly, it has been suggested that the falsetto notes may be formed by the division, into harmonic lengths, of the column of air in the trachea, which thus reciprocates the tone produced by the vocal cords; for, besides vibrating by reciprocation with a sounding body, the vibrations of which are isochronous with its own, a column of air may also vibrate by reciprocation, the number of its vibrations then forming a multiple of those of the sounding body. (Wheatstone.) But these more or less theoretical views are set aside by the direct observations of Garcia, who states that, during the production of the falsetto notes, the glottis is longer and wider, and that the edges only of the vocal cords are approximated, and offer little resistance to the air, whilst, in the natural voice, a certain depth of the surface of each cord is made to approach the other and to undergo vibrations; moreover, the cords vibrate more actively, the escape of air is more rapid, the notes cannot be so long sustained, and, lastly, the force of the air is weaker.

In old *age*, the muscular and nervous power are diminished, the structural elements of the larynx undergo degeneration, its cartilages become ossified, and other changes take place, which impair the strength of the voice, causing it to lose its tone, and to become weak, unsteady, and tremulous. The pitch of the voice is modified by changes in the temperature, and by the condition of humidity of the atmosphere; in cold, damp weather, it is frequently lowered by two or three notes. The voice of singers sometimes becomes dissonant; the muscles of vocalization being fatigued, are no longer under the control of the will, and their movements become unsteady; moreover, the state of constant tension, to which the vocal cords are so frequently subject, from over-exercise, induces certain changes in them, which interfere with their healthy action.

In certain *diseases*, the lining membrane of the larynx becomes inflamed, ulceration ensues, and the voice is impaired or lost; so also in œdema of the loose areolar tissue beneath the mucous membrane of the glottis, which may be produced by inflammation of this membrane, or by any obstruction to the venous circulation through these parts, the voice is destroyed.

The glottis, besides being the organ of voice, acts as a *safety-valve*, preventing the accidental intrusion of foreign bodies, whether solid, fluid, or gaseous, into the windpipe. Its sensibility, and that of the parts immediately above it, is exceedingly delicate, so that it is admirably adapted for this purpose. The moment any solid, fluid, vaporous, or gaseous noxious substance comes in contact with the upper opening of the larynx, sudden and spasmodic closure of the glottis immediately takes place; sometimes coughing ensues, and thus the body is expelled from the air-passages. The closure of the glottis is due principally to spasm of the arytenoid muscles; probably, however, other muscles are also concerned in it.

The muscles of the larynx are placed under *voluntary*, *emotional*, *ideational*, *sensori-motor*, and *excito-motor*, or so-called *reflex*, control, by means of the superior and inferior laryngeal nerves, branches of the pneumogastric, and of the *motor* fibres given to the pneumogastric by the spinal accessory nerves. The functions of the laryngeal branches of these nerves have been determined by numerous experiments on animals. The superior laryngeal nerve is the so-called afferent nerve of the larynx, supplying fibres to the highly sensitive mucous membrane lining the air-passages in this situation; it contains, moreover, a few motor fibres for the supply of the crico-thyroid muscle, and in part also of the arytenoid. The inferior laryngeal nerve is the efferent or motor nerve of all the other muscles. Division of the inferior laryngeal nerve is immediately followed by paralysis of all the muscles of the larynx, except the crico-thyroid; the sensibility of the mucous membrane of the glottis, however, remains unimpaired; division of the superior laryngeal nerve causes a total loss of sensibility of the mucous membrane, whilst the movements of the glottis are unaffected. The application of a stimulus to the inferior laryngeal nerve causes contraction of all the muscles, except the crico-thyroid, this muscle alone undergoing contraction when the superior laryngeal nerve is irritated. When the pneumogastric, or its inferior laryngeal branch, is divided, the laryngeal muscles being paralyzed, the arytenoid cartilages are no longer under muscular control, but, yielding to the current of air, cause mechanical closure of the glottis, so that the animal dies asphyxiated, unless an opening be made in the trachea. Experiments on the spinal accessory nerve show that it also has a certain control over the muscles of the larynx.

The simple reflex closure of the glottis takes place in the case of sudden immersion in a noxious gas, when unaccompanied by sensation. The alternate opening and closing of the larynx, in the act of coughing up an irritating body, are sensori-motor movements, being associated with sensation. The momentary closure of the glottis, when under the influence of emotion or ideas, as in sobbing or laughter, affords examples of emotional or ideational reflex movements. Lastly, the larynx is under the control of the will, as when the glottis is closed by effort, or is variously moved in voluntary coughing, or in the production of the voice and speech.

SPEECH.

Speech, or the utterance of *articulate sounds*, is a modification of the sounds generated in the larynx, in their outward passage through the cavities of the nose and mouth. Though commonly associated with the production of voice, yet it does not necessarily depend on it; for in *whispering*, for example, words are articulated simply by the action of the mouth and fauces; no vocal tones are produced, there being a total absence of laryngeal vibrations, or vocalization, in the act. In whispering, the pitch of the sound varies in different cases, according to the natural pitch of the cavity of the mouth in each person. *Sighing* is another example of the production of sounds by the parts seated above the larynx, totally independent of any action of this organ; for when the vocal cords also are called into play, the sigh is converted into a groan. The letters of the alphabet, with but few exceptions, may be articulated without, or with only imperfect, laryngeal action, by drawing in the breath.

Articulate sounds are divided into vowels and consonants.

The true *vowels*, or *open sounds*, as they are called, are generated in the larynx. They are merely uninterrupted vocal tones, variously modified in their outward passage, by alterations in the shape of the parts of the oral cavity through which they pass; thus, in uttering the pure vocal sounds *ā*, *ă*, *e*, *o*, *u*, pronounced respectively as in the words far, fate, ell, old, and in French words containing the *u*, one and the same sound produced by the vibrations of the vocal cords is converted into five different sounds, by changes in the position of the tongue, and by the gradual prolongation of the cavity of the mouth, by means of the lips; the most natural of these vowel sounds, or the one most easily uttered, is the broad *ā*. In the same manner, the *diphthong* sounds *i*, *ei*, *eu*, and the sounds of *y* and *w*, at the beginning of words, are vocal tones, modified by further changes in the shape and form of the mouth.

Consonants, or *shut sounds*, are entirely formed in the parts above the larynx, and are so named, because most, if not all, of them, can only be sounded *consonantly*, that is, with another sound or vowel. They require, for their production, a shutting or valve-like action to take place, either between the lips, as in pronouncing the letters *b*, *p*, and *m;* or between the upper teeth and lower lip, as in the case of *f* and *v;* or between the tongue and the palate, as *d*, *g* hard, *c* hard, *k*, *q*, *t*, *r*, *l*, and *n;* or between the tongue and teeth, as in the production of hissing sounds, such as *c* soft, or *s*, and *z*. The *compound articulate sounds*, as *j*, or *g* soft, *ch* soft, *ch* guttural, *ph*, *sh*, *th*, *ng*, and *x*, are produced by modifications, or combinations, of some of the other pure consonant sounds. The aspirate *h* is produced by an increased expiratory effort, made with the mouth open, before a vowel or other sound.

Those consonants which are produced by, or connected with, a sudden stoppage of the breath at a certain point, the opening leading from the pharynx to the nose being quite closed, and all the respired air passing through the mouth, are called *explosive* consonants. They are of two kinds: the simple explosive consonants *b*, *d*, and *g* hard; and the aspirate explosives, *p*, *t*, *k;* these, when uttered, are unaccompanied by a vocal sound, that is, they are not attended with intonation of the voice. Those consonants which can be pronounced without a complete stoppage of the breath previous to their utterance, are called *continuous;* some of these sounds are developed by the passage of the air, with a degree of friction, through the mouth; in this way, the consonants *v*, *f*, *s*, and *z*, are produced; others are produced by expiration through the nose only, as *ng*, *m*, and *n*. In uttering the letters *l* and *r*, the air escapes through the nose and mouth; in pronouncing the first of these, the air escapes at the sides of the tongue; in pronouncing the second, the tongue undergoes a vibratory movement. All the continuous consonants can be pronounced with a vocal sound, except the aspirate *h;* and some of them can be pronounced either with or without vocal intonation. Consonants have also been named according to the seat of their production; thus *p* is called a *labial*, *t* a *palatal*, *n* a *nasal*, and the Gaelic *ch* a *guttural* consonant; but this classification is exceedingly artificial and incorrect; for the greater number of articulate sounds are the result of the conjoined action of the mouth, lips, palate, and upper part of the air-passage.

Many sounds can be generated in the mouth, or throat, totally independent of any laryngeal action; thus, the smacking or *clicking sounds*, which occur in some of the African languages, are produced merely by separating the tongue sharply, from the hard or soft palate; in the emission of such sounds, neither breath nor voice is requisite. Many other familiar sounds, such as *kissing*, and smacking the lips as an expression of relish, are of a similar character. *Whistling*, also, is wholly unconnected with the voice, being a true mouth-sound, dependent only on breath, and resulting from the vibration produced by the friction of the air against the margins of the opening. In *laughing*, on the contrary, the sounds given forth are true vocal tones convulsively repeated.

Imperfections of speech, such as *lisping*, *stammering*, or *stuttering*, are due to errors in the action of the organs of speech. Stammering is almost always caused by some irregular action of the nervous centres, and is chiefly produced by temporary spasm of the glottis, associated with embarrassment in other parts concerned in articulation. It may originate in nervousness, or fright, and sometimes in imitation or affectation. By patient and persevering practice, founded on an accurate perception of the erroneous movements, and their correct substitutes, or by the recovery of self-confidence, these imperfections may generally be remedied. *Dumbness* is not, in any way, necessarily connected with defective development of the organs concerned in the production of speech; for *deaf-mutes* can be taught to speak, and acquire a rude kind of language. This last is an affliction conjoint, from birth, with deafness, the ear no longer serving as a guide for the purposes of articulation. Some mutes, however, are not deaf; the absence of speech, in such cases, being due, either to a malformation in the organs employed, or else to some defect in that part of the central organ of the nervous system connected with its production. It is said that persons who have become deaf, and remained absolutely so for many years, may forget how to speak, and so become dumb.

The nature of the peculiar kind of speech called *ventriloquism*, is obscure. It was supposed by Magendie to be produced in the larynx, by variously modifying the voice, so as to imitate the changes imparted to it by distance. It has also been thought to be simply produced by articulating during the act of inspiration. According to Müller, the sound of the voice peculiar to ventriloquism, may be imitated, after taking a deep inspiration, so as to cause the protrusion of the abdominal viscera by the descent of the diaphragm, and maintaining this muscle in its depressed condition, by speaking during a very slow expiration, performed only by the lateral parietes of the chest, through an exceedingly narrow glottis. Many attempts have been made by Faber, Kempelen, and others, to construct speaking automata, but with very partial success, the separate sounds being imitated, but not the mode of combination necessary for the production of Speech.

Voice in Animals.

The organ of voice in the different orders of Mammalia, presents various degrees of development, being in some, highly complex in structure, in others more simple in form; but in all, presenting a general anatomical and physiological resemblance to the vocal apparatus of Man. Among the so-called Quadrumana, some are provided with large sacs, situated between the thyroid cartilage and hyoid bone; these exercise a considerable influence in modifying and increasing the resonance of the voice. The acute tone and hoarse quality of the cry in some of the monkeys of the old continent, are due to the presence of laryngeal sacs. The intensity of the voice, in some species of American monkeys, the howlers, is very great; this is dependent both on the size of the epiglottis, and on the existence of cavities of considerable magnitude in the thyroid cartilage and hyoid bone, which, communicating with the ventricles of the larynx, and with other cavities above them, called the laryngo-pharyngeal sacs, cause a remarkable increase in the resonance of the laryngeal apparatus. The bray of the ass probably depends, in great part, on the presence of two large sacs situated between the vocal cords and the inner surface of the thyroid cartilage. Among the Marsupials, some, as, *e. g.*, the kangaroo, possess membranous vocal cords which fold upon themselves; the arytenoid muscles cannot therefore stretch them. A few Mammalia are unprovided with vocal cords, and are therefore mute, as for example, the giraffe, armadillo, and porcupine. The vocal ligaments are also absent in the Cetacea; some of these are able to utter a lowing or bellowing sound; this is produced during the act of expiration, when, the mouth being closed, they expel the water, with which that cavity has become filled in the act of feeding, through the nasal opening, or openings, in the upper part of the head: the noise produced in this act cannot be regarded as a vocal sound. The voice of Mammalia is always in a minor key.

The vocal apparatus in Birds differs altogether from that of Mammalia, both as regards its anatomical structure, and the manner in which sounds are produced by it. Birds are provided with a larynx corresponding in situation to that of Mammalia, presenting, however, a marked contrast in many parts of its structure; and being, moreover, totally unconnected with the production of sound. This part of the respiratory apparatus is called the *superior larynx.* The true organ of voice, the *inferior larynx*, is situated at the lower end of the trachea, immediately before it bifurcates to form the two bronchi. It presents various modifications, both in form and structure, in the different Orders of birds; in some, it forms an exceedingly delicate and complicated apparatus; it is a double organ, except in the parrot and a few other birds, and is almost always symmetrical. It is composed of several of the lower rings of the trachea, united together, so as to form a tube, which presents, at its lower extremity, two projections, an anterior and a posterior one; passing between these, in most birds, is a slender rod of bone, called the *os transversale*, which serves to connect them together; this part of the trachea opens below by two oval apertures, into the right and left bronchi. The upper margin of the bony rod gives attachment to a fine delicate membrane, the *membrana semilunaris*, which is directed upwards; connected with its lower margin is another membrane, called the *membrana tympaniformis*, which is, in reality, formed by that part of the wall of the bronchus which is made up simply of membrane; for the bronchi, in Birds, are not formed of complete rings of bone and cartilage, joined by membrane, like the windpipe, but are only partially strengthened by bony or cartilaginous pieces, so that their adjacent or opposed parietes are membranous; and it is these parietes that form the tympaniform membrane. In some birds, this membrane is very small and rudimentary; it is highly developed in singing birds, and still more so in speaking birds; it is continuous with the membrana semilunaris, and can therefore, when thrown into vibrations, render the latter tense. The inferior larynx is provided with special muscles, in the more perfect forms, with five pairs of muscles, the office of which is to regulate the distance between the vocal membranes, and to alter their tension by elevating the first cartilage of each bronchus; in some birds, however, the inferior larynx has no special muscles. The entire organ is absent in vultures.

The seat of voice in birds has been shown by experiment to reside in the inferior larynx, the tympaniform and semilunar membranes being the analogues of the vocal cords in Mammalia. Division of the trachea about its centre, in singing birds, does not arrest vocalization, although the notes emitted are, of course, rendered feebler by the existence of such an opening. Again, if the bronchi, together with the inferior larynx, be removed from the body, and air blown through them, the resulting sounds closely resemble the natural notes or cries of the bird. The absence of vocal ligaments, or cords, in the superior larynx, at once excludes all idea of its being concerned in vocalization; it no doubt, however, exercises a considerable influence in modifying the vocal sounds. It may, moreover, be seen to move simultaneously, with the mouth during the action of the inferior larynx, in singing birds. It is yet undetermined whether the sounds produced by the inferior larynx, are the result of the vibrations of a reed- or tongue-like apparatus, or whether they are caused by the friction of a column of air against the margins of an opening. In those birds provided with a simple vocal apparatus, such as the duck, there can be no doubt that this is reed-like in character; for when in action, the margins of the membranes can be seen to vibrate, and the resulting sound is, besides, exactly analogous to that produced by elastic membranes when thrown into vibrations. An opinion has been entertained by some, that the varied and manifold tones, which singing birds, provided with a more highly-developed inferior larynx, are able to produce, are due to sonorous vibrations in a column of air, excited by friction against the margins of the aperture of the inferior larynx, in the same manner as the sound in whistling is produced by the friction of the air against the margins of the lips; but even admitting this to be true, the vibrations of the air must, in their turn, communicate vibrations to the vocal membranes. The range of the voice in Birds is usually within an octave, but in some it is much greater. As in Mammalia, the voice is always in a minor key. The various notes are produced, not only by changes in the degree of tension of the vocal membranes, but by differences in the force of the blast of air, and by changes in the length and degree of tension of the trachea, or of other resounding parts.

The trachea presents various modifications in different birds. In some, it is much longer than the neck, forming a folded tube, which consists of a vast number of rings, as in the capercailzie, stork, crane, and wild swan; in the flamingo, these rings are said to be about 350 in number. In some birds, the trachea is wider above than below, and in others, it is dilated at various points.

In Reptiles, the vocal organs are of a more simple character than in Mammalia and Birds, though they present many different degrees of development in the various Orders and Genera. The vocal cords are absent in the true Serpents, which therefore possess no voice, properly so-called; the hissing sounds produced by them, result from a forcible breathing through a soft glottis. In frogs, amongst the Amphibia, the larynx opens directly into the bronchi, these animals being unprovided with a trachea; the intensity of the sounds emitted by the male frog, is much increased by the presence of membranous sacs at the sides of the neck, which undergo considerable distension during croaking. Some frogs possess membranous vocal cords. In others, the organs which emit sound, consist of two solid rod-like bodies, the anterior ends of which are fixed, whilst the posterior extremities are free, and are directed towards the orifice of the bronchus on either side.

Fish, when taken out of water, make a peculiar noise; this is caused by the sucking or flapping movements of their mouths or gill-coverings. A few fish, provided with an air-bladder opening into the pharynx, probably produce sounds by the compression of this organ. The tambour fish produces continuous sounds when under water; its air-bladder is of large size, and is exceedingly muscular.

A certain number of Insects can produce sounds. In some, as for example, the Coleoptera or beetle tribe, the blue-bottle flies, and humble-bees, the sounds are said to result from the passage of air through their spiracles, constituting what is termed humming or purring. In others, such as the crickets and grasshoppers, the sounds are caused by the friction of file-like organs, upon the margin of membranous drums, which are formed upon the wings, and the sound is called *stridulation*. The pitch of the sound of the cricket is very high, being produced by 4096 vibrations in a second. The noises in certain species are dependent on the rapid movements of folded membranes, called the *timbales*, which are inclosed, one on each side, in a cavity on the under part of the abdomen, and which are moved by the contraction and relaxation of special bands of parallel muscular fibres. It was long since shown that in the Dipterous Insects, such as the flies and gnats, which have only two wings, the buzzing sound is totally independent of the action of the wings in flight, for these may be cut off, and yet the sounds are still heard; they are produced by the rapid vibration of two lateral appendages named *halteres*, which are rudimentary posterior wings. The noise emitted by the sphinx, or death's-head moth, sometimes characterized as a shriek, is also produced by the friction of parts connected with the mouth and proboscis.

The remaining and lower members of the animal kingdom, being mostly aquatic, have no vocal or even other special sonorous apparatus.

SENSATION—THE REGULATION OF MOVEMENT—THE PSYCHICAL FUNCTIONS.

NERVOUS EXCITABILITY—CONDUCTILITY—SENSIBILITY.

The vital property of *sensibility*, which belongs to the nervous tissues, consists in the power of being so excited by various external or internal stimuli, as to produce the phenomena of sensation. But this definition does not express the whole of the vital properties of the nerve-tissues; nor does it accurately define those which are concerned in the sensory phenomena alone. For example: stimuli applied to the nerves, may not only excite *sensation*, but may also induce contractions, or *motion*, in the muscles, accomplishing this, either by the direct conduction of a stimulus along a nerve, or else by the conduction of a stimulus to a nervous centre, whence it is reflected, along another nerve, to the muscles. Again, in the phenomena of sensation itself, it is necessary to distinguish between the *excitation* of a nerve by a stimulus, its *conduction* along the nerve, and its final effect upon, or reception by, a nervous centre.

The kinds of *stimuli* which will excite a nerve, are the same as those mentioned in speaking of the muscular contractility, viz.: mechanical stimuli, such as tickling, scratching, pricking or pinching, bruising, stretching, tearing or cutting; the stimulus of heat or cold; irritants and chemical substances, such as mustard, acetic acid, salt, or mineral compounds—some acting by removal of water, as sulphuric acid or chloride of calcium; others by abstracting fat, as ether; and others by solution of the albuminoid substances, such as alkalies. The action of these stimuli on the nerves engaged in sensation, differs; acids, for example, causing much pain, and but little or no muscular contraction. Light, and also some chemical substances, produce effects without any recognizable change in the nervous substance; such are the oxygen of the blood, sapid and odorous particles, and certain products of the nutrition or waste of the tissues, as well as many medicinal and poisonous substances. Electrical stimuli, whether galvanic, magnetic, or frictional, and even the electrical currents existing in animal tissues, likewise excite the nerves. But nerve is distinguished from muscle, by being excitable through certain stimuli called vital, originating in its own substance, or acting upon it from without, such as the reflex and mental stimuli, which cannot call muscular contractions into play directly, *i. e.*, without the intervention of nervous substance. The excitability of particular nerves is also aroused, in peculiar ways, in the exercise of the special senses, as, for example, taste and smell by chemical action, hearing by vibrations in a surrounding medium, and sight by the undulations which cause the sensation of light. Psychical stimuli also excite the nerves: whether these are ideational, emotional, or volitional, they proceed from the brain, being themselves sometimes induced by external causes, and sometimes originating primarily in the great nervous centres, from the operations of the instinct, the memory, the reason, or the will.

When a stimulus of any kind, whether mechanical, chemical, electrical, or vital, acts upon the living nervous substance, be it composed of nerve-fibres, or of nerve-cells, it produces an impression on that nerve-substance, and excites within it some particular change; and the property, by virtue of which this takes place in the nerve-substance, whether composed of fibre or cell, has been called its *excitability* or *neurility*. But the nerve-substance, whether vesicular or fibrous, not only receives such an impression from a stimulus, and is excited to such a change, but it possesses the property of conducting that impression, or the change produced by it, in certain definite directions; and this property might be spoken of as *conductility*. When such an impression, or excited change, is thus conducted, or propagated, simply along a nerve-fibre, or through a nerve-cell on to a nerve-fibre, and thence to a muscle, it induces or excites, as we have seen, the contraction of that muscle, and so exercises what is called a *motor* function; but when such impression, or change, is excited in, or propagated along, a nerve-fibre simply, or through nerve-cells also, up to the common sensorium of the body, it then exercises a *sensory* function, and ends in the production of a sensation. The anatomical seat of such sensation, so far as we are at present able to trace it, is exclusively in the nerve-cells, which therefore may be said to possess a peculiar kind of *receptivity*. Hence, though both the nerve-fibre and the nerve-cell are excitable, and may be said to possess excitability, and though both can also conduct or propagate onwards, changes excited in them by stimuli, and therefore possess conductility, yet only the nerve-cells, so far as we know, possess receptivity, or true sensibility, or, as already said, can become the anatomical seats of sensation.

It must therefore be understood, that the term excitability, employed in a general sense, includes simple excitability, conductility, and sensibility properly so called. Furthermore, the nerve-fibre is wholly incapable of being acted upon directly, by mental stimuli, whether these be ideational, emotional, or volitional; for the reaction of these mental states upon the nervous system, takes place exclusively upon, or within, the gray matter of the nervous centres, and therefore, it is fair to presume, upon or in the nerve-cells, of which that gray matter is principally composed. Hence, these nerve-cells appear to possess beyond the simple excitability to general stimuli, conductility, and the peculiar receptivity, which is essential to sensation, a special or more exalted kind of excitability, which is called into play under mental or psychical stimuli, by the changes produced in the gray matter, in the formation of ideas, emotions, and will.

The excitability of a nerve remains for a time, after its separation, by cutting or bruising, from its nervous centre; but its conductility is of course immediately destroyed. The excitability of a divided motor nerve, is at first even slightly exalted; but it then slowly diminishes, and finally disappears, the nerve itself becoming converted into cellular and fatty tissue; the nearer the point of division to the nervous centre, the quicker these changes occur. Sensory nerve-fibres, when divided, undergo degeneration, both in their central and peripheral portions; in the former, because they can no longer conduct impressions, and in the latter, on account of their separation from the central organ. Excitability is thus shown to be an *inherent* property of nerve, but requires, for its permanent maintenance, a connection with a nervous centre. It is destroyed by mechanical injuries, by chemical changes, and by very strong electrical shocks. Moderate stimulation increases the excitability; stronger stimuli weaken or destroy it. When exhausted in regard to weaker stimuli, it may still be called into play by more powerful or by other kinds of stimuli; a succession of different stimuli is not so exhaustive as the continuance of the same stimulus.

The sudden application of any stimulus, is one condition of its action; for the mechanical stimulus of pressure gradually applied to a motor nerve, and increased in intensity, produces no convulsions, even if the nerve be ultimately destroyed. Sudden mechanical shocks alone produce muscular contractions. Again, a ligature slowly tightened around a sensory nerve, causes merely a numbness, and at length total insensibility; whereas, if it be suddenly tied, intense pain is produced. The electrical current has been supposed to act, by causing mere mechanical disturbance in the particles of the nerve-fibres; but this view is inconsistent with the known changes in the electrical state of nerves, when acted upon by galvanic currents, or by mechanical, or other, stimuli.

The action of particular stimuli deserves notice. Thus, the influence of *chemical* stimuli upon nerves is slow, probably on account of the resistance offered by the neurilemma or sheath; they are said to act more readily on sensory than on motor fibres, the former of which are, moreover, acted upon by a greater variety of chemical stimuli. Strong solutions of ammonia, and alcohol, powerfully stimulate the motor nerves; so also do solutions of nitrate of potash and hydrochloric acid, and even very weak solutions of soda or potash. Certain powerful agents, such as bisulphide of carbon and strong mineral acids, destroy the nerve so quickly that no convulsions ensue. On injecting water into the vessels of a muscle, strong contractions take place, due, it is supposed, to the effect of the fluid on the fine terminations of the nerves (Schiff); but if water be applied to the trunks of the nerves, no movements occur. The gradual abstraction of water from a nerve, is not followed by muscular contractions; but if rapidly effected, tetanic spasms are produced. Certain poisons are found to lessen or destroy the nervous excitability, acting more or less suddenly in different cases. Some of these, as narcotics, for example, if applied locally to a nerve, will deaden its excitability at the point of application only; but, if introduced into the blood, they operate generally. The nerves are never the channels by which poisons are conducted into the system. However the sensory nerves are affected by heat or cold, it is only changes of temperature that are recognized by the sensorium, as *thermal effects;* but extreme heat or cold produces pain. In the frog, the motor nerves are so affected by a temperature of 130° Fahr. as to produce convulsions, but these soon pass off, through a loss of excitability, which, however, reappears on cooling of the nerve. In the other direction, convulsions are caused by exposure of the nerve to a temperature of 25° Fahr. These movements are more sure to occur when the alterations of temperature are rapid (Eckhard). The nervous excitability in the frog, is said to be exalted by temperature as high as 113°, but a still higher temperature diminishes or destroys it. A heat of 158° is followed by complete loss of nervous power; though, by a cooling down to 122°, it is possible to restore it. *Electricity*, applied methodically, may also restore nervous excitability, although, if applied indiscreetly, it may destroy it. A proper supply of *blood* to the nervous substance, is absolutely indispensable. If the aorta of a rabbit be tied, and the spinal cord be exposed as quickly as possible, no pain is produced by even the strongest irritation of the cord; in less than a minute, the voluntary control over the muscles is lost, the hind limbs are retracted, and irritation of the spinal nerves produces no signs of pain, though, for a certain time, it will excite movements. On removal of the ligature around the aorta, sensation, and, somewhat later, voluntary motion, are restored. Undue excitement exhausts the excitability of a nerve, producing numbness in a sensory part, and paralysis of motion in muscles; but rest will sometimes again restore the nervous excitability. Disuse diminishes and destroys it. Defective nutrition is at first accompanied by exalted excitability, but is subsequently followed by a state of depression. In motor nerves, the excitability is, for a short time, increased after death, this increase lasting longer in the neighborhood of the muscle. Its disappearance after death, takes place from the nervous centres to the muscles, near which it lasts the longest.

Molecular changes undoubtedly occur in nerve-fibres, when these are stimulated; and, it is said, more readily in sensory than in motor fibres, the latter requiring much more powerful stimuli. These changes are not well understood. Microscopic examination reveals no physical alteration, however powerful the stimuli applied. It has been stated, however, that quiescent nerves have a neutral chemical reaction; but that this is altered to an acid one when they are excited. (Funke.) In the mode of their operation, nerves have been compared to telegraph wires, as performing an *internuncial* office, or the duty of conveying impressions intended to act as messages. The motor nerves have been specially regarded as electrical *discharging* organs, but the analogy here indicated is very rude.

When a stimulus is artificially applied to a nerve-fibre, it is probable that its effects are propagated longitudinally in both directions; but in the living body, stimuli are usually applied to nerve-fibres either at their distal extremity, as in the various sensitive tissues or surfaces of the body, or else at their central ends, as in some of the gray ganglia, or gray masses, of the nervous centres. The effect of a stimulus applied to the distal extremity of certain nerve-fibres during life, is propagated, or conducted inwards, towards a nervous centre;

hence it is called a *centripetal* action, and the fibre is spoken of as an *afferent* nerve-fibre; on the other hand, when the central extremity of another kind of nerve-fibre receives the stimulus, the effect of this is propagated outwards towards a muscle; that is to say, a *centrifugal* action takes place, and the fibre is called an *efferent* fibre. The efferent fibres terminate in muscles, and convey the effects of motorial stimuli; hence they are called *motor* or *motory* fibres. The afferent fibres have received two different names, according to the different offices which they serve. First, some afferent fibres convey the effect of impressions to certain parts of the gray matter of the nervous centres, and then, by a reflected action, which always takes place through gray matter, stimulate certain efferent or motor fibres, which, in turn, excite definite muscles to contract; such a mode of action of the nervous system, is called a *reflex* action, and the afferent fibres concerned in it, may be called *reflex afferent* fibres, and the efferent fibres concerned, *reflex efferent* or *reflex motor* fibres. The entire nervous apparatus employed in these reflex actions, viz., the afferent fibres, the gray nervous centre, and the efferent fibres, is also spoken of as an *excito-motor* nervous apparatus; and the phenomena resulting from its action, are named excito-motor phenomena, or *reflex acts.* Secondly, other afferent fibres convey the effects of impressions or stimuli upon them, to the common sensorium, and there produce *sensations proper;* these are called *sensory afferent* fibres, or simply, *sensory* fibres.

There is no anatomical difference discernible between the sensory, reflex, and motor fibres. Even between the nerves of common sensation, and those of the different special senses, there is no recognizable distinction, excepting as regards the comparative fineness of the fibres of the latter; but they are connected with different portions or masses of the gray matter of the sensorium. It is presumable that the difference in the functions of afferent and efferent fibres, depends on the direction in which, during life, the effects of stimuli are practically made to operate, and on the difference between the parts to which those effects are ultimately conveyed. In a motor fibre, the stimulus, or rather some state of the nerve-fibre produced by it, travels outwards to a contracting muscle; in an afferent reflex fibre, inwards to a reflex nervous centre; and in a sensory fibre, inwards to a sensitive nervous centre. Sometimes in the living body, a nerve is composed entirely of efferent or motor fibres; for example, the sixth cranial nerve. At other times, a nerve is composed entirely of afferent fibres; and of these, either the greater part may be purely sensory, as in the case of the nerves of the special senses of sight and hearing, viz., the optic and auditory nerves; or there may be, with the sensory fibres, many afferent reflex fibres, as in the case of the sensory branches of the first and second divisions of the fifth cranial nerve. More commonly, both efferent and afferent fibres, that is motor, sensory, and reflex, are combined together in the trunk of a nerve, as in the case of the third division of the fifth cranial nerve, and of all the spinal nerves. As we shall hereafter see, the afferent and efferent fibres, in this last case, are separated at the roots of the nerves, which are always double, and spring from different points of the spinal cord.

The white nerve-fibres are excitable by artificial stimuli, and conduct the effects produced by these at and along all parts of their course; and the gray matter likewise has the same properties. During life, however, it is the peripheral extremities of the sensory and afferent reflex white fibres, which are chiefly excitable, whilst in their course up to the sensorium, they usually act as conductors only; and, again, it is the central ends of the motor fibres, which are chiefly excitable, whilst in the rest of their course to the muscles, they usually act as conductors only. But during life, the white fibres have no power, so far as we are aware, of completing a sensation; nor do they originate, or form the source of, a motorial stimulus; these two special properties or forms of nervous excitability, are limited to the gray matter. Hence the gray matter is said to be more highly endowed, and to constitute what are called active nervous centres. Besides being concentrated in masses, the gray matter has a more complex microscopical structure, and is more vascular than the white matter.

The conducting power of motor nerve-fibres is such, that it takes a certain appreciable time for the effects of a stimulus to travel along them. The rate of conduction in the frog has been determined by the following interesting experiment performed by Helmholz. An upright blackened cylinder, made to revolve so many times in a second by clockwork, named a *Kymographion*, has two pins brought in contact with its surface; an upper one, attached to a galvanic apparatus, serves to record the moment of entrance of an exciting current into the upper end of a long nerve; whilst a lower one, attached to the muscle supplied by the nerve, records the moment and duration of the contraction of the muscle, by rising as the muscle contracts, and so describing a curved line on the cylinder. The circumference of the cylinder, the number of its rotations per second, the length of the line described by the lower pin, *before* it begins to ascend, and finally the length of the excited nerve, furnish data for the calculation of the rapidity with which the excitability of the nerve is brought into play along it; in other words, the rate of movement of the nerve-change through the nerve. Quite recently, Helmholz has devised another, much more complicated, but more delicate apparatus, for determining this rate. In the motor nerves of the frog, at a temperature between 52° and 70°, the rate of conduction was found to vary from 81 to 126 feet per second. In warm-blooded animals, and in man, it has been estimated to be rather more than 200 feet per second. The rate of motion of an electrical current travelling along a metallic wire, has been shown to be 462,000,000 feet per second. Light travels about 40,000 miles in the same period. The rate of conduction of impressions in sensory nerves, has been calculated by Hirsch, at about 110 feet per second. The same observer states that the rate of propagation differs in regard to the nerves of touch, hearing, and sight; but the numerical results obtained by him are variable. Some difference, however, may exist in different nerves, for contraction of the iris in rabbits occurs quickly on irritation of the third cranial nerve, but more slowly after irritation of the fifth. (Budge.) The rate of propagation is moreover influenced by the strength of the stimulus, for powerful irritation of the ganglia belonging to the so-called sympathetic nerves, produces sudden reflex movements, although the normal character of the sympathetic is to act more slowly under the influence of moderate stimulation.

It has even been observed, in certain experiments, that muscular contraction takes place more slowly, the more distant the point of nerve which is excited; and the amount of difference in time, compared with the difference between the excited points of the nerve touched, enables the rate of propagation to be estimated. The *effect* of the stimulus upon a muscle has been shown to be greater, according to the length of nerve between the point excited and the muscle. Speaking generally, the force with which a muscle, excited through its nerve, contracts, is proportional to the force or intensity of the stimulus applied to the nerve. When one nerve is excited, a neighboring nerve lying close alongside it, may be affected, and so groups of muscles may be called into play. If a muscle be loaded with a certain weight, the commencement of contraction, when it is excited through a nerve, is somewhat delayed.

Nerves have been supposed to conduct impressions after the manner of the propagation of vibrations in tense cords, or by undulations in the fluid contents of the nerve-fibres, or through the agency of an imponderable ether; but such views are entirely speculative.

Electrical Phenomena in Nerves.

Nerves, like muscles, are conductors, though not such good conductors, of electricity; like muscles, they have electrical currents passing through them, even through small portions of them, during life, when they are in their normal condition, and in a quiescent state; and, lastly, like muscles, they are as excitable by electrical currents, as by any other stimulus. But nerve is distinguished from muscle, not only by being a feebler conductor of electricity, but by exhibiting various peculiarities of behavior, especially as regards its intrinsic electrical currents when under the influence of other extrinsic exciting currents or other stimuli. The *proper nerve-current,* discovered by Du Bois-Reymond, exactly like the muscular current, runs *within* the nerve, from the interior to the surface; and there is, by analogy, ground for concluding that, outside the nerve, it also passes, like the muscular current, *from the surface to the cut ends;* hence, in a separated portion of nerve, the surface is positive and the ends are negative, currents, as indicated by a galvanometer, passing from the equator in each direction, to the ends of the cut piece. The nerve-current may be shown, by placing a portion of the divided sciatic nerve of a frog, still connected with the leg, with its surface in contact with one cushion of the apparatus already described (p. 138), and its cut end with the other cushion. In a completely separated portion of nerve, the current is equally evident, whether the peripheral or the central cut end be brought against one cushion, whilst the surface touches the other; and the effect is much increased by doubling the piece of nerve, and applying both cut ends to one cushion, and the centre of the loop to the other. The nerve current is, however, more difficult to detect than the muscular current, being many times weaker; but, as in the case of that current, it must be remembered that only a portion of the proper current of the nerve operated upon, or, as believed by Du Bois-Reymond, only a secondary *derived* current, can be made to pass through the circuit of the galvanometer. The nerve current ceases in the dead nerve. Budge alone regards it as an artificial current, of doubtful existence in the living nerve; but its presence is, by others, universally admitted. To explain this electrical condition of the living quiescent nerve, its ultimate molecules have been supposed, as in the case of muscle, to be either single molecules with a *peripolar* arrangement, that is to say, with an equatorial positive band all round them, and with the two extremities negative (Diagram D); or else to be composed of a series of double molecules, having their corresponding poles placed towards each other (Diagram F, *a*). When a nerve is excited to action, its normal current, like that of muscles, undergoes a diminution, and this takes place whether the stimulus be galvanic, or mechanical, or chemical, such as salt and strychnia. This is most evident, when interrupted electrical currents are used to stimulate the nerve, and the muscles are tetanized. According to Du Bois-Reymond, the current may even be reversed; and a portion of a nerve so altered, has its cut ends neutral or positive to the longitudinal surface, instead of negative. In this condition, the conducting power of the nerve is lessened. The nerve regains its normal conditions, on being placed for a time between pieces of muscle.

The resemblances between nerve and muscle, in regard to their electrical currents, however, are not complete; for the electrical condition of a nerve is capable of being altered in a peculiar manner, by the application of a continuous galvanic current, which we shall here speak of as the *exciting current*, to a distant portion of the nerve; for, in such case, the normal current is altogether changed, according to, and in obedience with, the direction of the exciting current. If, for example, a portion of a nerve, Diagram E, 1, *a*, is connected with the galvanometer, by being placed on the moist cushions of the apparatus, represented in Diagram A, the normal nerve current passes *within* the portion of nerve, *a*, in the direction of the arrow, *i. e.*, from the cut end to the surface of the nerve. When now a constant exciting current is applied to *another part* of the nerve, by means of a galvanic cell B, in a direction, as marked by the arrow, *b*, corresponding with that of the nerve current in the part *a*, then the strength of this latter current is increased; but if, as shown in 2, the direction of the exciting current at *b* is opposed to that of the normal current in *a*, then the strength of the latter is diminished. Furthermore, if, as in 3, a portion of nerve is placed on the cushions, with the points of contact equidistant from its centre, so that the normal nerve currents passing from the middle or equator towards the ends or poles of the nerve counterbalance each other, as is well known, no effect is produced on the galvanometer needle; but when an exciting current is passed, as from the cell B, upwards or downwards, through a portion of the nerve as at *b*, beyond the portion included in the galvanometric circuit, then a current is immediately manifested in the part *a*, included in the gal-

Diagram E.

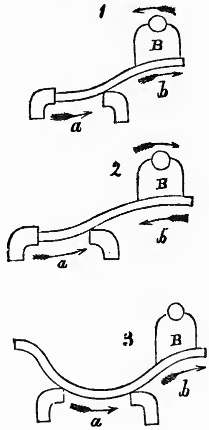


Diagram E exhibits the experiments by which an altered condition, called *electrotonus*, is shown to be produced in a nerve. 1, *a*, portion of nerve placed on the cushions of the galvanometric apparatus, *within* which piece of nerve, the normal current passes, as shown by the arrow; *b*, portion of the nerve beyond the apparatus, stimulated by a constant current from a cell B, in the direction indicated by the upper arrow, and therefore producing in this part of the nerve a current in the direction of the arrow *b*, *i. e.*, *corresponding* with the normal nerve current at *a*. The result is to *increase* the force of the current in the part *a*. 2, *a*, as before; *b* shows the course of a constant current made to pass from the cell B, through the outlying part of the nerve, running in the *opposite* direction to the normal current produced in the part *a*. The result is to diminish the force of this latter current in *a*. 3 shows a nerve so placed on the cushions, that no current passes through the galvanometer from the part *a*; but when a constant current is made to pass through the part *b*, from the cell B, then a current in the *same* direction is generated in the part, *a*, as shown by the arrow.

vanometric circuit, flowing, as shown by the two arrows, in a direction corresponding with that of the exciting current. In other words, the electrical condition of the *whole* piece of nerve, and not only that of its excited portion, is altered by and *obeys* the direction of the exciting current. To explain the controlling influence of the exciting current on the normal nerve current, the molecules of the nerve are supposed to be thus affected. As already stated, these are assumed to be, in the quiescent state, either *peripolar*, Diagram D, or to be composed

Diagram D (repeated).

Diagram D is here repeated, as it shows the supposed *peripolar* condition of the nerve-molecules, as well as that of the muscle-molecules, on which the normal current of those tissues is said to depend.

of pairs of unipolar molecules, with their corresponding poles turned towards each other, Diagram F, *a;* but under the influence of the exciting currents, they are supposed by Du Bois-Reymond to be so acted on, as to become *dipolar*. On the former supposition, of the nerve consisting of rows of single peripolar molecules, a shifting or alteration of their polarity is assumed to occur; but, on the latter supposition, every other molecule is imagined to undergo a change in its polarity, or seems to turn half-way round, as shown in *b*, Diagram F. This new condition of the nerve, as regards the electrical state of its molecules, is spoken of as its *electrotonicity*.

Diagram F.

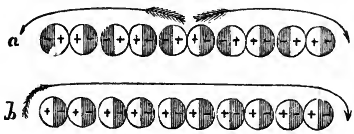


Diagram F shows a further view of the supposed electrical constitution of the nerve molecules, and also of the change in them, supposed to be produced in the state of electrotonus, or the electrotonic condition of nerves. *a* shows the supposed double constitution of the nerve molecules, each pair making up a composite peripolar molecule in the normal nerve. *b* shows how, by the half revolution of every other molecule, the whole chain may obey the direction of an exciting current or stimulus, and become *electrotonic*, *i.e.*, its molecules may assume the electrical character of those in any ordinary galvanic circuit. The arrows show the direction of a current outside such rows of molecules, as it would pass through a galvanometric circuit connected with them.

This *electrotonic* condition is so important, that we are justified in again comparing the effects of electricity on muscle and nerve, so as clearly to impress upon the mind this distinction between those two important tissues. When a muscle is excited to contract by any kind of stimulus, its normal electrical current is simply diminished; even if the stimulus be itself electrical, no other result seems to happen, and no further alteration of the electrical condition of the muscle takes place. But in regard to nerve, besides the diminution in the proper nerve current, which takes place as the result of the application of all kinds of stimuli, the electrical stimulus, when applied to a part of a nerve, by means of a continuous galvanic current, not merely diminishes the normal current through that part, but induces a particular and obedient change in the electrical polarity of the nerve-molecules of the neighboring parts also, and thus throws not only the excited portion, but the neighboring portions likewise, above and below, into the electrotonic state. It is more marked when the exciting current is strong; and less so, the greater the length of the excited portion of the nerve. It is also more perfect in the portions of nerve immediately preceding or succeeding the part excited; it becomes weaker, as the distance from that part increases upwards or downwards, and at last it disappears in both directions, the normal nerve current pursuing its usual course.

But not only is the occurrence of electrotonicity in a nerve, a character which distinguishes that tissue from muscle; but what is even more important, certain changes in the characteristic physiological property of the nerve, that is to say, in its excitability to stimuli, or its conducting power, simultaneously take place. Thus, when an exciting current, Diagram G, B, is passed through a portion, *a*, of a nerve, going to a muscle, *m*, so as to produce the electrotonic condition above and below it, the portion, *c*, of the nerve, lying outside the excited

Diagram G.

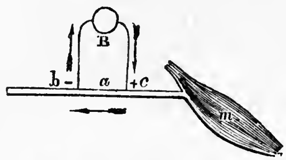


Diagram G illustrates the phenomena of an electrotonus and cathelectrotonus; and the changes in the physiological property of excitability of a nerve, accompanying those states. *a* is a portion of a nerve, supposed to be distributed to the muscle, *m*. B is a cell giving a constant current in the direction of the arrows, and passing through, from the anode, or positive pole +, to the *cathode*, or negative pole —, through the part of the nerve *a*. The part of the nerve marked *c*, is said to be in the state of *anelectrotonus*, and has its excitability diminished; the part marked *b*, is said to be in a state of *cathelectrotonus*, and has its excitability increased. In the portion of the nerve marked *a*, the excitability is heightened in the neighborhood of the part *b*, and lowered in the part near *c*. Somewhere between *b* and *c*, is a point where no change in the excitability occurs.

part, which is next to the *positive* pole +, and therefore *behind* the point of entrance of the current, has its excitability or its power of conduction *lessened* or diminished, whilst the portion, *b*, of the nerve next to the *negative* pole —, and therefore *in front* of the point of exit of the exciting current, shows an *increase* or heightening of its physiological properties. In other words, of the two parts of the nerve beyond the current, the part, *c*, next the entering current, has its properties diminished, and the part, *b*, next to the point of exit of the current, has its properties heightened. As the positive pole of a galvanic circuit is called the *anode*, the electrical condition of the nerve near that pole is called *anelectrotonus*, and manifests a lessening of the excitability; whilst, as the negative pole is called *cathode*, the condition of the nerve at that part, is named *cata-electrotonus*, or *cathelectrotonus*, and exhibits a heightening of the nervous irritability. Between the two poles, *a*, the nerve is also similarly affected; the part nearest *b*, has its excitability exalted, and the part nearest *c*, has it lowered. Somewhere in this piece of nerve, is a point where no change occurs. The position of this point moves nearer to the negative pole of that current, as the exciting current is made stronger, until the whole piece of nerve, *a*, has its excitability diminished; whilst, as the current is made weaker, this point travels towards the positive pole of the current, until the excitability of the whole piece, *a*, is heightened. It has further been proved that the excitability or conductility of an electrotonized nerve, is not only lessened or heightened in intensity, but that it responds to stimuli generally, more slowly than in the healthy nerve. Moreover, it appears that a constant exciting current of a certain strength, arrests the power of a motor nerve to produce muscular contraction by, as it were, holding in check the effect of other motorial stimuli upon the nerve. This action is called *inhibition*, and the current producing it, the *inhibiting* current. Lastly, as we shall immediately more particularly describe, an excited motor nerve produces contractions in a muscle, not during the *continuance* of its electrotonic state, but only at its *commencement* and *end;* and it appears to result from still more intimate observations, made by competent experimenters, that contraction takes place at the *moment of occurrence* of the *cathelectrotonic* state, but at the *cessation* of the *anelectrotonic* state. The power of producing these contractions in a muscle, is therefore dependent, not only on the strength of the current, but is modified by its particular direction, upwards or downwards, through the nerve. The change of state produced by irritation of nerve fibres is, moreover, sometimes propagated to neighboring fibres, so as to excite concurrent movements or sensations; or it may even extend to neighboring branches, or collateral nerves. Thus, if the sciatic nerve of a frog be detached from the spinal cord, and one of its two chief branches (tibial and peroneal) be cut across, above the point where it enters the muscles, and be stimulated by electricity, the muscles supplied by the other branch contract, owing to the production of the electrotonic state, not only in those fibres of the trunk of the nerve which belong to the divided branch, but also in those which belong to the undivided branch.

The phenomena produced by the application of electrical currents to motor nerves, are very complex. The effects are more marked, the further apart, and the more obliquely the poles are brought in contact with the nerve experimented upon. The chief facts hitherto observed may be thus summarized. A uniform and constant current produces no muscular contraction; but when very strong, as already stated, it inhibits the effect of other stimuli. When a constant current is varied in its intensity, then contractions take place at the moment of variation. It is by interrupted currents that contractions are normally produced, and these generally occur both when the current is made, and interrupted, or closed and opened, *i. e.*, as just stated, at the *commencement* and *end* of a current, and not during its steady continuance; but these phenomena are not constant, as we shall immediately see. With weak currents, the contraction occurs at the making, closure, or commencement of the current; with strong currents, at both the making and interruption, *i. e.*, at both the beginning and end of the current. When these interruptions of the current become sufficiently rapid, the muscle is thrown into a state of constant contraction, or is tetanized. Descending and ascending currents passed along the nerve, are otherwise called centrifugal and centripetal, or *direct* and *inverse* currents, because the former pass in the same direction as the volitional stimulus, *i. e.*, from the nervous centre to the muscle, while the latter pursue the opposite course. They each produce peculiar effects in particular circumstances, either according as the current is weak or strong, or according as the limb operated upon, is attached to, or detached from the body, or, lastly, according as the excitability of the nerves and muscles is more or less perfect. The following table shows the results obtained by Ritter and Nobili:

	Direct Current.		Inverse Current.	
	Commencement.	End.	Commencement.	End.
Limb, attached to body, ...		*	*	
Limb, separate, vigorous, ...	*	*	*	*
Limb, separate, excitability lessened, . .	*			*
Limb, separate, excitability nearly gone, .	*			

But according to Pflüger and Heidenhain the results are modified by the strength of the currents employed, as expressed in the following table :

Strength of Currents.	Direct Current.		Inverse Current.	
	Commencement.	End.	Commencement.	End.
Weak, ...	*		*	
Moderate, ...	*	*	*	*
Strong, ...	*	Slight.		*

Valentin maintains that, with moderate currents, contraction occurs only at the closure, or commencement, of the current, whether this be direct or inverse ; any other results, he refers to the effects of injury to the nerve. With stronger currents, contractions occur at both the commencement and the end, the latter being the weaker. As regards very strong currents, Valentin's observations coincide with Pflüger's. Budge, however, has found that very strong currents produce contraction, both at the moment of closure and opening, whether they be direct or inverse. The different results arrived at by equally careful observers, indicate the necessity for yet further investigations in this difficult subject.

It has been shown that the muscular contractions are more intense, the further from the muscle, *i. e.*, the nearer to the nervous centre, the stimulus is applied; this proves either that the nerve is more irritable near its centre of origin, or that the energy of a nerve *increases* as it is propagated *onward* (Pflüger and Budge). The latter view is adopted by Pflüger.

The electromotive properties, or electrical currents, of sensory nerves, are precisely identical with those of the motor nerves, and so likewise they present identical electrotonic phenomena ; hence an argument is derived in favor of the opinion, that both kinds of nerve fibres may conduct impressions in each direction. But the physiological reactions of the sensory nerves are somewhat different. Thus, in their case, the strength of the current influences the results ; a continuous current causes *continuous* excitement, instead of interfering with the excitability, and so arresting its motorial effect on the muscles, as is the case in the motor nerves. When the limb is separate, and the sensibility is moderate, pain is excited through a sensory nerve, only at the end of a direct or centrifugal current, and at the commencement of an inverse or centripetal current, results which are the opposite of those observed as regards the muscular contractions (Pflüger); lastly, a constant current does not inhibit the sensorial conducting power of a sensory nerve.

The experiments which establish the numerous foregoing facts, are amongst the most difficult and refined in physiological science, and clearly prove an intimate relation between the *electrical* state and the physiological action of the nerves; but at present, the true relationship between these two conditions can only be matter of conjecture. It has already been mentioned that, in stimulating a motor nerve, a constant current produces no muscular contraction, so long as it is of uniform strength, or uninterrupted; but that a variation in the intensity of the current, or an interruption of the current, will produce contraction. Now, the result of applying any stimulus, whether mechanical, chemical, or electrical, to a nerve, is, as we have seen, to cause a *diminution* of the normal, or usual nerve current; and such a diminution or variation in the current, it is allowable to suppose, may determine the muscular contraction. Again, when a nerve is excited by an electrical current, and thrown into an electrotonic state, we have an alteration in the static current, and, besides this, a new one established in its stead; but contractions only take place at the commencement and end of the electrotonic state, not during its continuance—that is to say, at the *interruption* of the current. If, therefore, by any process taking place in the nerve cells of the gray matter, such momentary electrotonic states may be produced, contractions would necessarily occur when it was established, or when it was interrupted. Such an explanation of the action of the nerve substance is, however, at present hypothetical. The possibility of some internal change, of an electrical character, in a living tissue, influencing the excitability of a nerve, and so making the muscles supplied by that nerve to contract, is proved by the interesting experiment of causing the muscles of the so-called *rheoscopic limb* of a frog, to contract, by means of the stimulus of the altered electrical currents of the muscles of another frog's limb. The rheoscopic frog's limb consists of the hinder limb of a frog, denuded of its skin, and cut off just above the knee, but having the whole length of the sciatic nerve preserved uninjured, and still connected with the detached leg. Such a limb, sometimes also called *galvanoscopic*, serves, when insulated by being laid on a piece of glass, for the various experiments on the motor properties of the nerve; for the muscles contract when the nerve is pinched, scratched, irritated with saline solutions or acids, or when it is electrified, in which latter case the current must be made to pass, not directly across the nerve, but along some appreciable portion of its length. But the experiment to which allusion is made above, consists in laying the projecting portion of the sciatic nerve—of course uninjured—upon the muscles of another frog's leg, and stimulating those muscles to contract, by galvanizing their motor nerves at such a distance from them, and in such a manner, that no part of the exciting electrical current can directly reach those muscles. When this is done, the muscles contract, and, as we already know, this is accompanied by disturbances, *i. e.*, by intermittent diminutions in their normal current; and hence, in consequence of these variations, they excite the nerve of the rheoscopic limb, which is resting upon them, and this, in turn, causes contractions in the muscles of that limb. Here, then, is an example of a nerve excited, so as to cause contractions of its muscles, by the agency of electrical currents occurring in a living tissue, viz., in the muscles of another frog's leg. To succeed in this experiment, it is necessary that the nerve of the rheoscopic limb be placed, not merely across the contracting muscles, but obliquely or longitudinally for some little distance upon them. A very powerful exciting battery may be made, by placing a chain of skinned frog's legs one upon another.

Dr. Radcliffe, whose opinion on the passive nature of muscular contraction has been elsewhere mentioned, supposes that the electromotive condition of the nervous molecules, is not dependent on the existence within them, of *current* electricity, or continuous internal currents, but rather upon a *static* form of electricity. The current established through the galvanometer, by a portion of nerve, he believes to be only an *induced* current; and, to explain it, he supposes that nerves, or their nerve fibres, consist of two sets of electrical molecules—an external or *superficial* set, having their surfaces *positive*, and a *central* or axial set, having their surfaces *negative*. He further believes that the diminution or cessation of the obvious nerve current, when a muscle is in action, justifies the supposition that muscular contraction may depend, not on a direct stimulation of its fibres by the nerve current, or on a disturbance of the muscular current, but on the suspension or *absence* of the static currents, which are present in inactive, but living, nerve and muscle. The relaxed state of the muscle, he believes to be maintained by the *presence* of the static current. The rigor mortis, he likewise supposes to depend on a similar cessation of these currents. He also explains the electrotonic phenomena of excited nerves, in accordance with his peculiar views.

Nerve Force.

The phenomena which take place in nerve fibres and nerve cells, when excited to action by any stimulus, have led to the supposition that there is manifested within them at such times, a peculiar force, which is called the *nerve force*, or *vis nervosa*, just as the electric and magnetic phenomena produced in electric or galvanic, and magnetic apparatus, are supposed to be the result of an electrical and magnetic force, called either electricity or magnetism. Three different views are entertained respecting the nature of this nerve force. By some, it is regarded as a *special force*, proper to living nerve substance, a *vital force* wholly different, even in kind, to any other force in nature. By others, it has been considered to be the same as electricity, or a mere modification of it. A third view supposes it to be a special form of the common force of nature, correlated to electricity, and, through it, to all the other forms of that force.

In considering these views, it is necessary to bear in mind that there are many reasons why the physiological energy of nerve substance, or nerve force, is to be regarded as something different from electricity. First, if it were electricity, it would be conductible along a piece of copper or other metallic conductor; whereas, if a nerve be divided, and its cut ends be connected, by laying a piece of metal wire between them, the one portion of the nerve does not act when the other portion is excited; or, in other words, the nerve force cannot pass along the metal wire. Nerve fibres, or nerve cells, are the only structures along which the nerve force can be propagated. Secondly, cold diminishes the conducting power of nerves, for the nerve force; whereas it increases the conducting power of solids or fluids, for electricity. Thirdly, the crushing of a nerve, or tying it tight, and afterwards loosening it, interferes with the future passage of the nerve current; whereas the mere bruising of a wire, does not stop electricity from passing through it. It may be, however, that the case of an injured nerve, should rather be compared with that of a compound telegraph wire, in which the internal copper conducting wires are broken, whilst the outer supporting coils and coverings of iron wire, rope, and gutta-percha, are uninjured. Fourthly, as has already been mentioned, the nerve current travels at an extraordinarily slow rate, as compared with that of electricity. Lastly, from careful experiments performed by Pflüger, it appears that the nerve force increases in power, in proportion to the length of nerve excited; that is to say, the effect in causing muscular contraction is greater, the further from the muscle, or the nearer to the nervous centre, the nerve is excited; and so, in the reflex action of nerves, the nearer to the peripheral ends of the nerve the stimulus is applied, the greater the effect. It would seem, therefore, that either the nerve force *gathers strength* as it passes along a nerve, or excites the development of additional nerve force as it travels along. This peculiarity distinguishes it from electricity, which has no such power of exciting new force within a conductor, but rather tends gradually to become itself exhausted. From these various facts, it appears safe to conclude that nerve force is, at least, something different from electricity; and a force so far peculiar to living animals, and to specially organized living tissues in animals, viz., to *nerve cells* and *nerve fibres*, that it cannot be manifested, conducted, or propagated, excepting in and through those tissues. There remain, however, the further important questions, whether, and in what manner, it is related, or correlated, to electricity, and through it to the common force of nature. It has been shown by the physicist that mechanical force, producing motion, is correlated with and convertible into heat, heat into chemical force, chemical force into electrical force, and electrical into magnetic force; moreover, that each of these is correlated, and convertible into the other, or, indeed, any one of them into any other, all being thus interchangeable. Now, it is not supposed that the force acting in a nerve, is identical with electrical force, nor yet a peculiar kind of electricity, nor even physically induced by it, as magnetism may be; but that, in the special action of a living nerve, a force is generated, peculiar to that tissue, which is so correlated with electricity, that an equivalent of the one may, in some yet unknown manner, excite, give rise to, or even be converted into, the other. In this concatenation of the several forces of nature, physical and vital, the force acting in a nerve may also be correlated with chemical force, with the heat developed in the muscle, and even with the peculiar molecular motions which produce muscular contraction, and all its accompanying physical or mechanical consequences. Indeed, as it is more acceptable to the human mind to suppose that the quantity of force, like the quantity of matter in the existing order of nature, remains the same, and is never lost or annihilated, some such notion of the interchange of inorganic into organic, and of organic into inorganic force, must be entertained. On this view, the nerve force is, as it were, nourished from physical force, as the living substance of the nervous tissues is fed from the inorganic materials of the dead world. The nerve force here spoken of, is, however, merely that which is set free in the exercise of the properties of excitability and conductility, in both sensory and motor nerves. But, as already stated, we must leave unsolved the mystery of *sensation* and *consciousness*, as endowments of living matter, even when these are manifested in their simplest forms, in animals; and, in regard to the higher mental faculties, we can only recognize the co-operation of the same nerve force, as one necessary physiological condition of all such psychical phenomena in us.

The particular *functions* performed by the nervous system, are, as already stated, first, those of *sensation common* and *special*. Secondly, the regulation of all the movements of the animal body, whether these be reflex, emotional, ideational, or volitional; or whether they appertain to the animal, or to the vegetative functions, such as the movements of respiration, those of the alimentary canal, and the motions of the heart and bloodvessels. Thirdly, the nervous system is that part of the frame, through the agency of which, all mental manifestations occur. Lastly, the nervous system influences the nutritive functions of the body, either solely by its effects on the minuter bloodvessels, or, perhaps also, by some special control over, or interference with, the chemical processes of nutrition and secretion.

In the lowest animals, as we shall see, the nervous system disappears; and hence all their functions, whether animal or vegetative, are performed, so far as we can at present discern, independently of nervous substance.

In man and the higher animals, not only are both the animal and vegetative functions placed, more or less, under the control of the nervous system, but the anatomical connections between the different parts of this system are exceedingly numerous and intricate, and the physiological relation between the most distant parts proportionally intimate. Moreover, the paths and centres concerned in the functions of sensation, reflex and other motions, and psychical acts, are so structurally associated, that all parts of the body are more or less in sympathy with each other; and even the vegetative organs, though provided with their own nervous apparatus, may be so affected through the irritation of distant parts, that a strong light applied to the eye, will cause vomiting, and an emotion or desire will create palpitation of the heart. So widely diffused, indeed, are the phenomena of sensation, regulated motion, and psychical action in the body, that it is easier, instead of describing these functions in strictly physiological order, to treat of the functions of the several parts of the nervous system. To prepare the way for such an account, we must first give a description of this system.

THE STRUCTURE OF THE NERVOUS SYSTEM.

The nervous system in man, includes the *cerebro-spinal* nervous system, and the *sympathetic* nervous system. The former consists of a central part, composed of the *brain* and *spinal cord*, often designated together, the *cerebro-spinal axis*, and of a peripheral part, composed of *nerves* which spring from the brain and cord, and are named the *cranial* and *spinal* nerves. The sympathetic nervous system consists of numerous *ganglia*, connecting *nerve cords*, and branches or nerves; it is joined, by numerous short cords, with the cerebro-spinal system.

The Cerebro-Spinal Nervous System.

The protected position of the brain and spinal cord, within the cavity of the cranium and the spinal canal, as well as the mode in which the nerves escape from those cavities, have been already described (pp. 27, 30, Figs. 9 and 12); and the position of the sympathetic nerves in the thorax and abdomen, is mentioned at pp. 35, 36, and is further illustrated in Fig. 62.

The three protective *membranes* which cover the brain and spinal cord, viz., the *fibrous* membrane or *dura mater*, the *serous* membrane or *arachnoid*, and the *vascular* membrane or *pia mater*, have also been mentioned. The *dura mater* protects the brain and cord, forms supporting partitions between the right and left halves of the cerebrum, and between the cerebrum and cerebellum, and furnishes sheaths to the several cranial and spinal nerves; it likewise assists in forming venous channels or sinuses for the conveyance of the blood returning from the brain; in the cranium, it acts as an internal periosteum. The *arachnoid*, like other serous membranes, is a doubled membrane forming a closed sac, the purpose of which is to facilitate such motions of the brain and cord, as are inevitable in changes of their position, or of the state of their circulation. The spinal cord is specially supported by a long duplicature of the arachnoid, with fibrous tissue in it, on each side, named the *ligamentum denticulatum*, Fig. 60, *t*. Between the arachnoid and the innermost membrane, or pia mater of the brain and cord, are certain spaces filled with fluid, the *subarachnoid fluid*, which is said to support the great nervous centres as in a hydrostatic apparatus. Its usual quantity is about two ounces, but this varies in certain circumstances; in cases of extravasation of blood in the head, it is all absorbed; whereas, in wasting of the brain, it is increased to as much as twelve ounces. In the more slightly varying conditions of the circulation in the cranium, its quantity no doubt is perpetually changing; for when it escapes in fractures of the skull, or in injuries of the spine, it is very rapidly reproduced. It may also readily descend into, and ascend from, the spinal canal; and thus, or by absorption, may regulate the degree of pressure on the brain and spinal cord. When suddenly withdrawn, great disturbance of the functions of the brain ensues, but these are restored as it is reproduced. Pressure on the brain causes sleep, torpor, or coma; and the absorption of this fluid may, to a certain degree, remove the effects of pressure. The *pia mater* is chiefly formed of a congeries of small arteries, which here ramify and subdivide, before entering the cerebro-spinal nervous centres. The supply of blood to these organs is very large, amounting, it is said, to one-fifth of the total quantity of blood in the body, though the weight of the encephalon is only about one-fortieth of the weight of the body. The peculiarities of the bloodvessels in the cranium, and the regular and uniform distribution of the blood to the brain, will be described in the chapter on the Circulation. Ligature of the great vessels of the neck is quickly fatal, unless some collateral vessels continue to carry blood into the cranium. The snake charmers of India, sometimes produce, as a trick upon themselves or others, stupor and rigidity, by pressing below the base of the skull, probably by arresting the circulation through the brain. Rupture of the heart, or of the aorta, is followed by instant death, owing to a failure in the supply of blood to the brain. Syncope, or loss of consciousness and voluntary power, is a temporary suspension of the cerebral functions, owing to a deficient action of the heart. A decapitated head certainly may exhibit, for a time, reflex movements; but it cannot be known whether, and for how long, it retains sensibility.

The entire human brain, well named the *encephalon* (ἐν in, and κεφαλη, the head), is a solid but soft organ, which weighs, on an average, in the female, about forty-four, and in the male, about fifty ounces; ranging in the female, from thirty-nine to forty-seven ounces, and in the male, from forty-two to sixty-ounces. The mean difference between the male and female brain is about five ounces. The brain bears a general proportion to the weight of the body, and this probably explains the greater weight of the male brain; for in eighty-one males, the proportion of the brain to the body, was found to be as 1 to 36.5, and in eighty-two females, very nearly the same, viz., as 1 to 36.46. These were from persons who had died from exhausting diseases. The average proportion of the brain to the healthy body is about 1 to 41. The brain grows rapidly up to the seventh year, and at the eighth year appears to reach nearly its full size; then a slighter increase is observable up to the twentieth year, and even a slow augmentation up to about forty years; after fifty years, there is a slow diminution in weight, it is said of about one ounce for each decennial period.

In extreme cases, the brain has reached the weight of sixty-five ounces. (Cuvier's brain weighed upwards of sixty-four ounces.) In idiots, the brain is small, having been found to weigh from about twenty-five ounces to as low as ten ounces, in a female, forty-two years of age; and eight and a half ounces in an idiot boy, twelve years old; this is the smallest idiot brain on record. The proportionate weight of the brain to the body, in idiots, has been found as low as 1 to 144. The weight of the brain varies in the races of mankind, chiefly, however, it would seem, in harmony with their stature; for the cubical capacity of the cranium, which is a fair indication of the size of the brain, and in the European, on an average, measures about 80 cubic inches, is, in the large-bodied negro, about 70 cubic inches; in the smaller Bush tribes, about 60 cubic inches; and in the Hindoos, also of diminutive stature, though of fine organization, it is said to be as low as 47 cubic inches.

The entire brain, or encephalon, is made up chiefly of two parts,—an anterior upper part, much larger, called the *cerebrum* or *brain proper*, Fig. 12, *a*, and a smaller posterior and inferior part, called the *little brain* or *cerebellum*, *b*. Besides these, there are certain connecting parts at the base, constituting the *cerebral peduncles*, the *pons Varolii*, and the *medulla oblongata*. The cerebrum and cerebellum are supported at their base, on certain stalk-like parts called peduncles, from which a sort of main stalk, formed by the medulla oblongata, is prolonged out of the cranium into the spinal canal, forming the spinal cord. The *spinal cord*, *c*, is a cylindrical mass of nervous substance, which extends from the opening in the base of the skull, down to about the lower part of the body of the first lumbar vertebra, where it becomes pointed, *c*, and terminates in a slender membranous filament, which runs downwards, and is attached to the lower part of the canal in the sacrum. The continuation of the spinal cord upwards within the cranium, towards the peduncles of the cerebrum and cerebellum, is named the *medulla oblongata*, Fig. 60, *m;* it is of a pyramidal form, having its base turned upwards, and measures about one inch and a quarter in length. Just above the medulla oblongata, in front, is a broad transverse band of nervous substance, called, after an old anatomist, the *pons Varolii;* this extends laterally into the cerebellum. Issuing from above the pons, are the stalks or *peduncles* of the cerebrum; these are continuous upwards with the cerebrum, and downwards, through the pons, with the medulla oblongata and cord. The cerebellum, Figs. 12 and 60, *b*, is also connected by peduncles, with the back part of the cerebral peduncles, the pons and the medulla; thus its inferior peduncles attach it to the medulla, its middle peduncles are formed by the lateral extensions of the pons, and its superior peduncles join it to the back of the cerebral peduncles.

Supposing the entire brain or encephalon to weigh fifty ounces, the cerebrum would weigh about forty-four ounces, the cerebellum five ounces, the pons and medulla oblongata one ounce. The proportion between the cerebellum and the cerebrum is therefore about 1 to 8.8. In early life, the cerebellum is much less developed in proportion to the cerebrum, the ratio between the two being then as 1 to 13 or 15. The cerebellum acquires its maximum weight between twenty-five and forty years of age; its rate of increase, after fourteen, is proportionately greater in the female. In idiots' brains, owing to the want of development of the cerebrum, the cerebellum is disproportionately large, the ratio having been found to be about 1 to 4, or even as low as 1 to 2.6. The spinal cord weighs usually, on an average, one ounce and a half; its proportion to the encephalon is therefore about 1 to 33. The following numbers have been stated by Bourgery, to represent the relative weights of the several parts of the nervous centres in man: the cerebrum, 170; the cerebellum, 21; and the peduncles, and certain parts connected with them, named the corpora striata and optic thalami, with the pons Varolii and the medulla oblongata, 13. The whole encephalon is thus supposed to be divided into 204 parts.

The *cerebrum*.—In considering further the structure of the great nervous centres, it is important to bear in mind the primary fact, that they are composed, cerebrum, cerebellum, pons, medulla oblongata, and spinal cord, of two symmetrical halves, applied to, and united together, in various ways, along the middle line. Thus, the cerebrum itself, Fig. 57, is composed of two lateral halves, called the *cerebral*

Fig. 57.

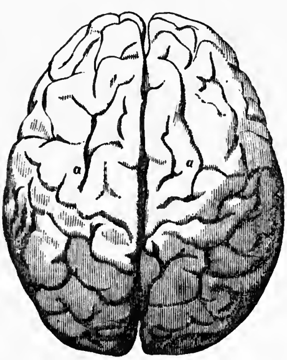


Fig. 57. Upper surface of the cerebrum of man, showing its subdivision, by the longitudinal fissure, into two lateral hemispheres, right and left; also the chief sulci and convolutions. The fissures of Rolando are the oblique fissures which commence near the middle line, and proceed outwards and forwards, marking off the frontal lobes, *a. a*, from the parietal lobes, which lie behind those fissures. The occipital lobes, forming the hinder extremity of the hemispheres, completely conceal the cerebellum.

hemispheres, *a*, *a*, which are united together, at the bottom of a deep fissure, named the *longitudinal fissure*, by a thick transverse band of nervous substance, called the *corpus callosum*, which, however, passes across, between the hemispheres, in only a certain middle portion of their extent, so that the latter, as shown on a horizontal section, Fig. 58, *a*, *a*, are completely separate, in front and behind it. It is in this longitudinal fissure that the falx cerebri, Fig. 9, *f*, dips down; whilst the tentorium is placed horizontally, between the hinder part of the cerebral hemispheres and the upper surface of the cerebellum. At the base of the cerebrum, its hemispheres are further connected by their respective peduncles, which are themselves united together in the middle line. Within the hemispheres, and between the corpus callosum above and the diverging peduncles below, are certain *cavities* in the interior of the cerebrum, called the *ventricles;* these cavities are roofed in, as it were, by the substance of the hemispheres, and by the corpus callosum, and are also closed below by the diverging peduncles, at the sides by the hemispheres, and in front by nervous substance passing down from the corpus callosum to the peduncles; but posteriorly, they are open, so as to communicate with the surface, and admit, into the interior of the ventricles, an extension of the vascular covering of the brain, or pia mater, together with many large bloodvessels.

Fig. 58.

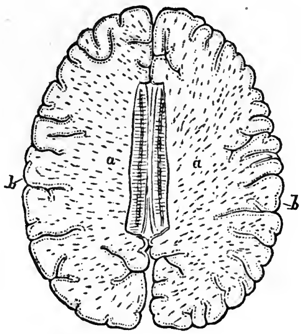


Fig. 58. Horizontal section through the cerebrum, to show the mode in which the two hemispheres, *a, a,* are joined together by the transverse band of white substance, named the corpus callosum. In front and behind this, the longitudinal fissure separates the two hemispheres. *b, b,* is the section of the cortical substance; *a. a,* of the medullary. The section also shows the depth of the sulci, between the convolutions.

Each cerebral hemisphere is described as consisting of certain parts called *lobes*, which were formerly named *anterior* or *frontal*, *middle* or *parietal*, and *posterior* or *occipital.* The anterior lobe was said to be separated from the middle, by a deep fissure, seen on the side of the brain, named the *Sylvian fissure*, but the limits between the middle and posterior lobes were arbitrarily fixed by different anatomists, according to their position in regard to the cerebellum. Certain well-marked fissures, which have been observed on the outer and inner surface of the hemispheres, serve however to divide its mass more definitely into such lobes. For example, one long fissure, called the *fissure of Rolando* (see description of Fig. 57), passes obliquely forwards, from a little distance behind the vertex, and separates an anterior or frontal region from a middle or parietal region, the former nearly corresponding with the frontal lobe, but including a small portion of the parietal lobe. Further back, another fissure, seen on the inner surface of the hemisphere (see description of Fig. 59), and called the *internal perpendicular fissure*, marks off a posterior lobe or region, which is now described as the *occipital* lobe. Below that, on the under and inner surface of the hinder part of the hemisphere, is a horizontal fissure, called the *fissure of the hippocampus;* this separates the occipital lobe above, from the lowest portion of the middle lobe, now named the *temporal lobe*, which is further separated, on the outer surface of the hemisphere, from the frontal and parietal lobes, by the Sylvian fissure. On opening out the Sylvian fissure, a fifth lobe is seen, named the *central lobe* or *island of Reil.* Of these lobes in the perfect human brain, the frontal is the largest, the temporal and parietal are next in size, then the occipital, and, lastly, the central lobe is the smallest. Each of these lobes has its surface moulded into numerous tortuous and com-

Fig. 59.

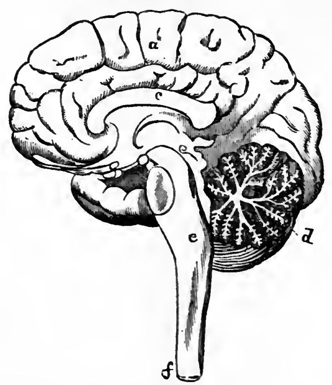


Fig. 59. Longitudinal median section through the human cerebrum, cerebellum, cerebral peduncles, pons Varolii, medulla oblongata, and part of spinal cord. *a*, inner surface of the right cerebral hemisphere, showing its sulci and convolutions; the fissure, running upwards and a little backwards, above the cerebellum, marks off the occipital lobe from the parietal. *c*, is the section through the corpus callosum, the large white commissure, which connects the two hemispheres; below this, are the ventricles of the brain, and then the cut surface of the right peduncle; the section of the pons Varolii, is the part level with the cerebellum. *d*, the section through the cerebellum, showing the branched white substance, penetrating the gray matter, and forming the so-called *arbor vitæ*. *e*, section of the medulla oblongata; *f*, the same of a part of the spinal cord.

plicated elevations of the cerebral substance, which have been named the *gyri* or *convolutions;* these are marked off from each other by secondary winding fissures called *sulci.* Most of these convolutions have long since been separately described and named by Flourens and others, but a more systematic account of them has been recently given by Gratiolet, in their respective groups of frontal, parietal, temporal, occipital, and central. The convolutions of each lobe are connected together at the bottom of the sulci, and also more or less at their ends. So also the different lobes of the hemispheres are not distinctly severed from each other, but are united at the bottom of the divisional fissures, and also round the ends of these fissures. On the outer surface of each hemisphere in the human brain, owing to the absence of the external part of the so-called perpendicular fissure which exists more or less marked in the Quadrumana generally, the line of distinction between the parietal and temporal areas or lobes in front, and the occipital lobe behind, is obliterated by many sinuous bridges of nervous substance, called the *connecting* convolutions. The general plan of the convolutions in the two hemispheres is the same; but, in point of detail, there is a want of exact symmetry, a character which seems to be associated with a higher development of any given type of cerebrum.

From the preceding description, it will be seen that the free convoluted surface of the cerebral hemispheres, is of enormous extent, in comparison with the small surfaces, which are connected below with the peduncles, and across, from side to side, with the corpus callosum. This free surface, indeed, occupies at least five-sixths of the internal surface of the hemispheres corresponding with the parts turned towards the longitudinal fissure; it extends likewise all over the outer surface, and over the base, with the exception of the comparatively small part connected with the peduncles. It corresponds with the internal surfaces of the frontal, temporal, and parietal bones, with a portion of the occipital bone, and with the upper surface of the tentorium.

The whole of this highly complex free surface of the hemispheres, which appear like efflorescences upon the summit of a stalk, Fig. 59, *d*, is composed essentially of *cineritious* or gray nervous matter, here named the *cortical* substance, Fig. 58, *b*, consisting chiefly of nerve cells, but also traversed by a number of very fine white fibres, and extremely well supplied with bloodvessels. The two principal purposes fulfilled by the superficial position of the gray matter, and by the great complication of its surface, are that of allowing a more perfect communication with the numerous fibres connected with it, and that of obtaining the greatest possible amount of gray nervous matter within a comparatively small space; moreover, this large surface facilitates the free and abundant supply of blood to the important gray cortical substance of the cerebrum. The surface of the human cerebrum has been computed by Baillarger to be equal to about 670 square inches. The thickness of the cortical substance is usually about one-fifth of an inch; but this varies, as well as the depth of the sulci, which is a measure of the height of the convolutions; in both these respects, the adult human brain exceeds that of the infant, or of the aged; and a deficiency in both, has been observed in idiots, and in the less civilized races of men. The color and structure of the cortical substance are not uniform in its whole depth; but it presents three different zones, viz., an *outer pale zone*, in which two narrower ones may be recognized; a *middle grayish zone*, and an internal *reddish-yellow zone*, in which four narrow ones, two reddish-yellow, and two white, may be discerned, thus making *seven* zones, or layers, in all. The nerve cells, also arranged in layers, are most abundant in the middle zone, and least so in the external one, in which the white fibres are very numerous. The nerve cells are provided with numerous branching offsets, *i. e.*, are markedly multipolar. The white fibres of the deepest zone are chiefly radiating in their direction, but some also pass parallel to the surface of the cerebrum, and so give rise to the appearance of zones. As the white fibres proceed through the gray matter, they become finer, and many of them end in the processes of the nerve cells. In the external zone, they are finest of all, and many of them again spread out parallel with the surface, in the paler streaks of the outer zone, where they form loops, or are connected with nerve cells. The object of the intricate arrangement here described, appears to be to multiply the nerve fibres, which, by successive connection with layers of branched cells, are rendered finer, at the same time that they are enormously increased in number, and form almost infinite communications amongst themselves, and with the nerve cells.

The internal substance, *a*, *a*, of the hemispheres, named the *medullary* substance, is white, and is chiefly composed of white nerve fibres of very small diameter, which are ultimately connected with those found in the cortical substance. They may be regarded as forming several systems. First, there is a system of short *intrinsic commissural* fibres immediately beneath the gray matter, which connect adjacent or even remote convolutions. Secondly, there exists another smaller but doubtless important system of intrinsic *longitudinal commissural* fibres, which serve to connect the several lobes of each side, and also the so-called optic thalami and other parts, with the occipital and temporal lobes. The chief longitudinal band constitutes a part called the *fornix*, situated in the ventricular cavities beneath the corpus callosum; besides this, there are the *tænia semicircularis*, also within the ventricles, and certain other bands above the corpus callosum, and within the convolutions resting immediately upon it. Thirdly, there is a system of *transverse commissural* fibres, which pass from all regions of one hemisphere to the corresponding regions of the other, and form the large cross band called the *corpus callosum*, Fig. 59, *c*, above the ventricles; three other small transverse commissures, *anterior*, *middle*, and *posterior*, are situated in the floor of the ventricles. Lastly, there are found fibres, usually named the *radiating* fibres, or *ascending* fibres, but which, if traced from the cortical substance of the hemispheres downwards, may be called the *convergent* or *descending* fibres. These proceed from all parts of the superficial gray matter of the hemispheres, and converge towards the cerebral peduncles. Some of these convergent fibres have been described as crossing from one hemisphere, through the corpus callosum, to the other, and then descending towards the cerebral peduncles of that side, constituting therefore a *decussating* system of fibres; but this is not certain.

Above the cerebral peduncles are found, on each side, two large masses of gray matter, named the *corpus striatum* and the *optic thalamus*. The corpora striata lie in front of the optic thalami; both bodies partly project into the ventricular cavities, partly rest upon the peduncles, and have the rest of their surface embedded in the corresponding hemisphere, the radiating or convergent fibres of which, coming from all directions, pass into one or both of these masses of gray matter, but especially into the corpus striatum, which hence presents a *streaked* appearance on a section, as its name implies. It was formerly supposed that the convergent fibres from the hemispheres, traversed these large masses of ganglionic gray matter, and became directly continuous with fibres in the cerebral peduncles, the pons, the medulla oblongata, and the spinal cord. But, according to the most recent view, the fibres proceeding downwards from the cortical substance of the hemispheres, do not pass continuously through the corpora striata and optic thalami, into the cerebral peduncles, but terminate in the gray substance of those ganglionic masses, from which other fibres pass down into the peduncles, medulla oblongata, and spinal cord, and so become connected with the roots of the cranial and spinal nerves. Many, at least of the converging fibres, must stop short in the gray matter of these ganglionic masses, or they would certainly form a larger peduncle to each hemisphere than actually exists, and no instance has been detected of two or more white fibres uniting, in this situation, into a single one, and so accounting for their diminution in number. The convergent or radiating fibres of the cerebrum exceed the others in number; but the large proportion which the commissural fibres bear to them, appears to be one cause of the greater size of the cerebra of the higher animals, and especially of that of man.

Besides the corpora striata, and the optic thalami, other smaller masses of mixed gray and white matter demand attention. Thus, on the under surface of each frontal lobe, is found a small elongated oblong mass of gray matter called the *olfactory lobe*, which is attached by a narrow white peduncle, spreading backwards into three bundles, to the under surface of the frontal lobe, and to certain adjacent parts at the base of the cerebrum, in front of the Sylvian fissure; it is from these olfactory lobes, that the proper olfactory nerves, or nerves of smell, are given off to the nose on each side. Again, resting on the back part of the conjoined cerebral peduncles, overhung by the posterior border of the corpus callosum, and attached by white fibrous nervous substance, to the optic thalami, to the cerebellum, to the cerebral peduncles, and to the medulla oblongata, are four small eminences, named the *corpora quadrigemina*, two on each side of the middle line, and all blended together. They are white on their surface, but are composed of gray matter intermixed with many white fibres, running transversely, obliquely, and longitudinally: it is from these that the optic tracts, or roots of the optic nerves, or nerves of sight, chiefly take their origin. Two other little gray masses on each side, named *corpora geniculata*, are also found in connection with the tract or root of each optic nerve. Supported above the corpora quadrigemina, is a little conical body, attached by minute white pedicles, to the surface of the optic thalami; it is named the *pineal body* or *pineal gland*, and was supposed by the celebrated Des Cartes to be the seat of the soul. It is larger in the child and in the female, than in the male; it contains two or more cavities, usually filled with a viscid fluid, and gritty matter, *acervulus cerebri*, composed chiefly of aggregations of the so-called amyloid bodies, mixed with earthy and a little animal matter. The substance of the pineal body, contains pale roundish cells, and a few nerve fibres. Lastly, projecting downwards from the base of the brain, between the diverging cerebral peduncles, and connected with the floor of the ventricular cavities, is a tubular peduncle, which supports a nut-shaped mass, named the *pituitary body* or *hypophysis cerebri*. It weighs from five to ten grains, and, in the adult, is solid and firm. It is composed of an anterior larger, and a posterior smaller and deeper colored lobe, both, however, being very vascular. The anterior lobe especially, has been found to present a structure resembling, somewhat closely, that of the thyroid body, which is one of the so-called ductless glands. (Sharpey.) In the posterior lobe, a few nerve tubes are found. The use of this body, and that of the pineal gland, are entirely unknown.

In front of the pituitary body, the optic tracts of the two sides coalesce, or decussate, to form the *optic commissure*, from which the right and left optic nerves then proceed forwards to the eyeballs. It remains to be added, that in the interior of the cerebral peduncles, which are composed of white substance externally, there is also diffused a large quantity of gray or ganglionic nerve substance.

The ventricles of the cerebrum, mentioned so frequently above, are five in number, and were, by the old anatomists, considered of special importance, and to be the residence of what were then called the *animal spirits;* but they are really the remains of a simple cavity, formed by the folding back of the hemispheres, in the progress of their development, and gradually complicated in shape, owing to the projection of the corpora striata and optic thalami into them, and to the extension of the white cerebral substance, in various directions, round about them. As already stated, they are roofed in by the corpus callosum, and by its lateral extensions into the hemispheres; whilst in front, at the sides, and below, there are the corpora striata and optic thalami, the cerebral peduncles, and certain layers of nervous substance connecting those parts. The two largest chambers of these ventricular cavities, are the two *lateral ventricles*, right and left, one belonging to each hemisphere. Each lateral ventricle presents a central part or body of the cavity, and three prolongations named the *cornua* or *horns*, viz., an *anterior cornu* or horn, which passes into the frontal lobe, a *middle* or *descending cornu*, which curves backwards and outwards, and then downwards, forwards, and inwards, into the temporal lobe, and the *posterior cornu*, which passes backwards and outwards, and then inwards, in the occipital lobe. The descending cornu contains, besides the posterior ends of the fornix already mentioned, and other parts, a projection or ridge in its floor, called the *hippocampus major;* and in the posterior cornu, is a similar smaller projection named *hippocampus minor;* between them, is the *eminentia collateralis.* Both of these so-called hippocampi are merely portions of the hemisphere, projecting into the ventricle, and corresponding with the bottom of certain more or less well-marked fissures, or sulci, on the surface. The *third* ventricle is situated in the middle line, near the base of the brain, between the optic thalami; it communicates with both the lateral ventricles, and with the fourth ventricle to be presently noticed. The *fifth* ventricle is a small independent cavity, situated in a septum of nervous substance, found between the two lateral ventricles.

The *cerebellum.*—This part of the encephalon rests upon the occipital bone behind the foramen magnum, and is covered by the tentorium. It consists, like the cerebrum, of two hemispheres, which, however, are more extensively united than those of the cerebrum, and in a different manner, by a median portion, similarly constructed to the hemispheres themselves, and forming, on the upper and under surface, the so-called middle lobe, or *superior* and *inferior vermiform*, or worm-like processes; a slight notch marks off the hemispheres in front and behind. Each hemisphere is composed of smaller parts or *lobes*, separated from one another by deep crescentic fissures. These lobes, as well as the vermiform processes, are highly subdivided on their sides and surface, by crescentic furrows, or *sulci*, into numerous parallel, thin *laminæ*, some of which may be traced continuously over the vermiform processes, from one hemisphere to another.

The superficial part of the cerebellum, even of its minutest laminæ, many of which are hidden at the bottom of the principal sulci, consists of gray or cineritious matter, named, as in the cerebrum, the *cortical* substance. It is composed of large multipolar nerve cells mixed with white fibres, and arranged in thin strata. The interior of the cerebellum consists of *white* or *medullary* substance, which projects into the various lobes, and thence again, in the form of thin plates, into the multitudinous laminæ; hence a vertical section through the cerebellum, made across its laminæ, presents a beautiful arborescent internal white substance, surrounded by foliated bendings of the gray matter, an appearance which has been named the *arbor vitæ*, or *tree of life*, Fig. 59, *d*. Embedded in the white substance of each hemisphere, is a plicated or folded sac of gray matter, open in the direction of the peduncles of the cerebellum, and having white substance in its interior. Owing to the indented gray line which they present when cut through, these masses of gray matter are named the *corpora dentata* of the cerebellum. The peduncles of the cerebellum, composed of white fibres, form three sets, as follows: First, a *superior* pair of *peduncles*, which pass upwards, at the back of the cerebral peduncles, to the corpora quadrigemina and adjacent parts; the white fibres of these peduncles, chiefly issue from the interior of the corpora dentata. Secondly, a *middle* pair, which cross below, and embrace, the peduncles of the cerebellum, and so form the pons Varolii. Lastly, an *inferior* pair, which pass down to the sides and back of the medulla oblongata, of which they form the so-called restiform bodies, and, by them, are connected with the posterior and lateral columns of the spinal cord. The superior peduncles of the cerebellum, may be said to be composed of *longitudinal commissural* fibres, uniting it to a part of the cerebrum; the middle peduncles form *transverse commissural* fibres, which connect the two cerebellar hemispheres together, and bring them into relation with the gray matter diffused in the substance of the pons Varolii, forming in fact its transverse fibres. Finally, the inferior peduncles are *longitudinal commissural* fibres, connecting the cerebellum with the medulla oblongata and spinal cord. It has been recently stated that all the fibres of the three peduncles of the cerebellum, proceed from, or end in, the interior of the folded sacs of gray matter known as the corpora dentata; and that it is from the outer surface of these sacs, that all the fibres reaching to the laminated gray matter on the surface of the organ, in reality proceed; the fibres of the superior and inferior peduncles are said to decussate within the cerebellum; those of the former, end in a mass of gray matter, in the back part of the cerebral peduncles; those of the latter, in the gray nucleus of the olivary body of the medulla oblongata. (Luys.) These statements require confirmation.

Beneath the superior peduncles, and bounded below by the back of the medulla oblongata, is a space, communicating, by a narrow canal, named the aqueduct of Sylvius, with the third ventricle of the cerebrum, and forming the so-called *fourth ventricle.*

The *Pons Varolii.*—This part, already frequently mentioned, is composed superficially of transverse commissural white fibres, which connect the two halves of the cerebellum. But its deeper parts contain, intermixed, however, with other *transverse*, *circular*, or *arciform* fibres, the numerous *longitudinal* fibres which are continued from the base of the cerebrum, and from the cerebellum to the medulla oblongata. The undermost longitudinal fibres connect the cerebral peduncles with the anterior pyramids of the medulla; whilst the fibres towards the back of the pons, partly serve to connect the cerebrum with the posterior and lateral columns of the medulla, and partly join the cerebellum to the restiform bodies of the latter. In the interior of the pons is found, moreover, a large quantity of diffused gray matter.

The *medulla oblongata.*—The medulla oblongata, Fig. 59, *e*, may be regarded as chiefly forming an extension downwards of the peduncles of the cerebrum, and of the inferior peduncles of the cerebellum. Like those parts, it consists of two halves, which, however, are only slightly marked off from each other, in the middle line, in front and behind. In front, is seen a slight median longitudinal fissure, which, moreover, is interrupted by numerous obliquely intersecting bands of white nervous substance. On each side of this fissure, are two narrow columns of white substance, named the *anterior pyramids;* outside these, are two oval eminences, named the olivary bodies; external to these, and therefore at the side of the medulla, are, in succession, the lateral columns, the tubercles of Rolando, the restiform bodies, and at the back, on either side of the middle line, the *posterior pyramids.* At the back of the medulla oblongata, the restiform bodies and the posterior pyramids, are seen to diverge as they are traced upwards; and the latter bound below an angular space, which is the *floor of the fourth ventricle.* On this floor are seen certain important eminences, two on each side, formed by special accumulations of gray matter, and giving origin to large nerves; certain white transverse streaks, which are the roots of the auditory nerves, are likewise seen; and, lastly, a pointed depression, directed downwards in the middle line, corresponding with the tip of the so-called *calamus scriptorius*, and leading into a canal in the spinal cord.

The *anterior pyramids* of the medulla oblongata, are composed entirely of white fibres, and are continuous upwards through the pons, with the under part of the peduncles of the cerebrum, and downwards with the anterior or lateral portions, or so-called *columns*, of the spinal cord. Most of the fibres of the anterior pyramids pass obliquely across the median fissure, partly to the anterior, but chiefly to the lateral, columns of the opposite side of the cord, so that the fissure here is interrupted, as already stated, by intersecting bundles of fibres, which form the so-called *decussation of the pyramids;* some of these are said to pass down into the posterior part of the spinal cord; a certain number of the outermost fibres of the pyramids do not decussate, but descend into the anterior columns of the cord on their own side. The *olivary bodies* consist, internally, of a folded or plicated sac of gray matter, open towards the centre of the medulla, and named the *corpus dentatum* of the olivary body; but there are numerous white fibres, within, and around, this ganglionic centre; the external fibres are continued downwards into the antero-lateral columns of the cord, and upwards into the under part of the cerebral peduncle; the fibres which proceed from the interior of the corpus dentatum, ascend to the corpora quadrigemina. The *lateral columns*, also composed of white fibres, descend from the cerebral, and middle cerebellar peduncles, to the sides of the cord, partly undergoing decussation below, and forming a transverse commissure above, behind the corpora quadrigemina. The *restiform bodies* consist of white fibres, including a ganglionic mass of gray matter; they connect the inferior peduncles of the cerebellum with the posterior and lateral columns of the cord. The *posterior pyramids*, composed of white fibres, descend from the upper or back part of the cerebral peduncles, to the posterior part of the lateral, and to the posterior columns of the cord; some of these fibres are said to decussate opposite the back of the pons. Embracing the upper part of the two halves of the medulla oblongata, are certain transverse sets of fibres, superficial and deep, named *arciform fibres*, which serve to connect together, not only the two halves of the medulla, but all its component masses of gray matter; many of these fibres are associated especially with the corpora dentata of the olivary bodies.

The gray matter of the pons, as already stated, is diffused amongst the longitudinal and transverse white fibres; but in the medulla oblongata, it is collected together into more compact and definite masses. Of these, the folded corpus dentatum of the olivary body, has already been described; the tubercle of Rolando incloses a rounded mass, which is continuous below, with the so-called posterior cornu of the gray matter of the spinal cord; the rest of the gray matter of the medulla is chiefly collected in symmetrical masses, situated in its posterior portion, closely contiguous, and more or less blended together; they constitute special ganglionic centres of origin of most important cranial nerves. In the lower part of the medulla oblongata, the gray matter becomes more concentrated, and more covered in behind by the white substance, until at length, it passes into the completely inclosed gray matter of the cord.

From the preceding account, it will be seen that the medulla oblongata, like the cerebral and cerebellar peduncles and the pons, is white externally; but it has gray matter intermixed with all its component parts, except with the white fibres of the anterior pyramid; moreover, the gray matter approaches very closely the posterior surface of the medulla, where it seems, as it were, to have its interior opened out.

The *spinal cord.*—The *spinal cord*, Fig. 12, *c*, Fig. 60, *c*, *c*, a cylindrical mass of nerve substance, forms the prolongation downwards of the medulla oblongata. It presents a shallow, open, anterior median fissure, and a deep, close, posterior median fissure, which mark it off into a right and left half, united together by a narrow, deep, central commissural part. In each half, are two slight longitudinal lines, serving to distinguish it into what are called the *anterior*, *lateral*, and *posterior columns*, a narrow band of the latter, next to the posterior median fissure, being named the *posterior median column.* Opposite to the lower part of the neck, and again towards its lower end, the spinal cord presents an increase of substance, forming the *cervical* and *lumbar enlargements* of the cord. At its lower end, opposite the first lumbar vertebra, it terminates in a point, which is fixed by a long filament, extending down the spinal canal, to the sacrum. The spinal cord is composed of white substance externally; but on making a

Fig. 60.

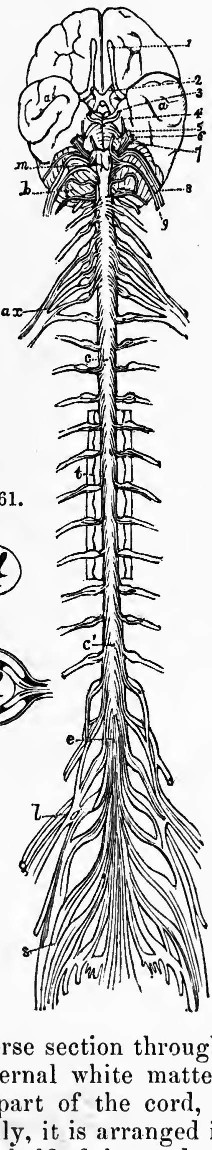


Fig. 61.

Fig. 60. Under surface or base of the cerebrum, and cerebellum, and of the pons Varolii and medulla oblongata, also the anterior surface of the spinal cord, to show the mode of origin of the cranial nerves from the base of the brain, and that of the spinal nerves from the spinal cord. *a, a*, cerebral hemispheres. *b*, right half of cerebellum. *m*, medulla oblongata; above this, is a transverse white mass, the pons Varolii. *c, c'*, the spinal cord, showing its cervical and lumbar enlargements, and its pointed termination. *e*, the cauda equina, formed by the elongated roots of the lumbar and sacral nerves. 1 to 9, the several cranial nerves, arising from the base of the brain and sides of the medulla oblongata. Below these, on each side, are the roots or origins of the spinal nerves, cervical, dorsal, lumbar, and sacral. In some of these, the double root can be seen, and the swelling or ganglion on the posterior root. *a x*, the axillary or brachial plexus, formed by the four lower cervical and first dorsal spinal nerves. *l*, the lumbar plexus. *s*, the sacral plexus, formed by the last lumbar nerve, and first four sacral nerves. *t*, shows a piece of the sheath of the cord cut open, and within it, a portion of the ligamentum denticulatum which supports the cord.

Fig. 61. A, a transverse section through the cord, to show the form of the gray cornua, or horns, in the midst of the white substance. B, shows the same parts; and also the membranes of the cord; and the anterior and posterior roots of a pair of spinal nerves springing from its sides.

transverse section through any part of it, it is seen to contain, within the external white matter, a quantity of gray matter. Quite in the upper part of the cord, this is somewhat diffused; but in the cord generally, it is arranged in the form of two crescents, Fig. 61, A, one in each half of the cord, and placed back to back, so that the horns of each crescent advance towards the shallow lateral longitudinal lines seen on the surface of the cord. Again, quite at the lower end of the cord, the gray matter loses its crescentic arrangement, and forms a slight rounded mass; and the white matter, which progressively decreases in quantity from above downwards, at length disappears, and at the extreme point, only gray matter exists. The white matter altogether, forms about seven-eighths, and the gray one-eighth, of the entire substance of the cord. The anterior horn of each crescent is short and thick; whilst the posterior horn is long and narrow. The posterior horn at its hinder and outer part, is more transparent than elsewhere, forming the so-called *gelatinous* portion, in which the nerve cells are large and multipolar; near the root of this cornu, on its inner side, is another peculiar column of gray matter, named the *vesicular* column. Throughout the whole extent of the cord, the gray matter of the one side is connected with the gray matter of the other, by what is called the *central gray commissure.* In the centre of this commissure, is the *central canal* of the spinal cord, a passage measuring about $\frac{1}{100}$th of an inch in diameter, and lined with ciliated columnar epithelium. In front of, and behind, the gray commissure, is a thin layer of white substance, which forms the bottom of the anterior and posterior median fissures. The cervical and lumbar enlargements of the cord, are principally caused by an increase of the gray matter.

Taking a general view of the brain and spinal cord, we see that the cerebrum and cerebellum are composed of gray matter externally, which gray matter, especially in the case of the cerebrum, forms a large proportionate share of its mass. On the other hand, the cerebral and cerebellar peduncles, the pons Varolii, the medulla oblongata, and the spinal cord, are composed of white matter externally, and of gray within. In the interior of the cerebrum and cerebellum, there is chiefly white substance; whilst in the interior of the cerebral and cerebellar peduncles, pons, medulla, and cord, we meet with gray matter. Special gray masses, however, are also found in the lower part of the interior of the cerebral hemispheres, resting upon the diverging and expanding peduncles, viz., the corpora striata, optic thalami, corpora quadrigemina, and corpora geniculata. The cerebellum also has its special internal gray corpora dentata, and so have the olivary bodies of the medulla oblongata. The course of the white fibres in the medulla oblongata and the spinal cord, and their connections with the masses of gray matter within those parts, and with the roots of the nerves, will be hereafter described.

The *cerebro-spinal nerves.*—These nerves are divided into two sets, called the *cranial* nerves, and the *spinal* nerves, according as they pass to their respective destinations through openings in the base of the cranium, or through the intervertebral foramina between the several vertebræ.

The *cranial nerves.*—These consist of nine pairs. The parts usually defined as the *first* pair, or the *olfactory nerves*, Fig. 60, 1, are really extensions of the cerebrum, and should be named the *olfactory lobes.* They are attached to the anterior cerebral lobe by three roots. The true olfactory nerves, or nerves of smell, arise from these lobes; they are very numerous, and pass through minute openings in the ethmoid bone, which forms the roof of the nose; within the upper part of that cavity, they spread out beneath the mucous membrane, and supply branches which advance to its surface to receive the stimulus of odors.

The *second* pair, the *optic nerves*, 2, or *nerves of sight*, arise on each side, by flat white bands, named the *optic tracts*, the fibres of which may be traced from the optic thalami, corpora quadrigemina, and corpora geniculata, and, it is said, even from the occipital lobes of the cerebral hemispheres. These tracts pass forward on the sides of, and beneath, the cerebral peduncles, and meet in front, as already mentioned, at the *optic commissure;* from this, the optic nerves proper are given off in front, and pass through the optic foramina in the sphenoid bone, to enter the bottom of the orbits, whence they proceed forwards to the back of the eyeballs. There, each nerve piercing the thick coats of the eyeball, spreads out in its interior to form the *retina*, which receives the stimulating impressions of light. At the optic commissure, a portion of the fibres of the optic tract continue into the corresponding optic nerve; another portion passes over into the optic nerve of the opposite side, thus forming a partial *decussation;* certain transverse fibres pass from one optic *tract* to the other, doubtless running back to the brain on each side; whilst other transverse fibres pass from one optic *nerve* to the other, serving to associate the retinæ of the two eyes; these are not directly continuous with the fibres of the optic tracts.

The *third* pair, *motores oculi*, or *motor nerves of the eyeball*, 3, arise from the inner surface of the cerebral peduncles, having deep origins from the gray matter there; a few fibres also spring from the corresponding corpora quadrigemina. They enter the orbit, and supply all the muscles of the eyeball, except the superior oblique and the external rectus. This nerve also sends branches, called ciliary nerves, which penetrate the coats of the eyeball, and supply the ciliary muscle, as well as the circular fibres of the iris.

The *fourth* pair, or *pathetic nerves*, 4, the smallest of the cranial nerves, arise from the back of the cerebral peduncles, and passing forwards, outside the peduncles, a little below the corpora quadrigemina, enter the orbit, and supply a single muscle of the eyeball, viz., the superior oblique or trochlear muscle; hence it is also called the *trochlear* nerve.

The *fifth* pair, 5, named the *trigeminal* nerves, because they divide into three chief branches, and *trifacial*, because these three branches appear on the face, are the largest of the cranial nerves. They arise from the sides of the pons Varolii, by *two* distinct *roots*, viz., a larger, softer root, which enters a crescentic ganglion, called the *Gasserian ganglion*, from which the three great divisions or branches of the nerve are given off; and a smaller and firmer root, which passes beneath the ganglion, and joins the third division only of the nerve. Both the roots of the fifth nerve arise from the gray matter in the pons and medulla oblongata. Of the three divisions or branches, the *first* or smallest, the *ophthalmic*, enters the orbit, and there supplies the eyeball and all its appendages; it gives branches likewise to the mucous membrane of the nose and the adjacent sinuses, and finally supplies the skin upon the crown of the head, the forehead, and the root and point of the nose, Fig. 62. The *second* division, or *superior maxillary*, supplies branches to the lining membrane of the nose, and Eustachian tube, to the sinus in the upper jawbone, to the palate, to the upper teeth and gums, and to the skin upon the side of the nose, the cheek, and upper lip. The *third*, or largest division, the *inferior maxillary*, supplies branches to the muscles of mastication, an important branch to the anterior two-thirds of the tongue, named the *gustatory nerve*, or nerve of taste, common sensory branches to the lower teeth and gums, the floor of the mouth, and the skin of the external ear, temple, lower part of the cheek and face, lower lip, and chin; and, lastly, branches to a few neighboring muscles, and to the parotid gland. All three of the divisions of this large nerve, give off sensory branches; but only the third division supplies motor branches. The three divisions of the fifth nerve, are connected by some or other of their smaller branches, with certain ganglia of the sympathetic nerve, and also with the facial nerve.

The *sixth* pair, or *abducent nerves*, *abducentes oculorum*, 6, arise from between the pons and the medulla oblongata, receiving fibres from both these parts. They supply a single muscle of the eyeball, viz., the external rectus, which abducts the eye; hence the special name of these nerves.

The *seventh* pair of cranial nerves, 7, consist, on each side, of *two portions*, one soft, destitute of a firm neurilemma, named the *portio mollis*, the other harder and round, named the *portio dura;* these are distinctly different nerves. The *portio mollis* is the *auditory nerve*, or nerve of hearing; it arises at the back of the medulla oblongata, from the floor of the fourth ventricle, and coursing forward, immediately behind the pons, passes from the cranial cavity into an opening in the petrous portion of the temporal bone, named the internal auditory meatus or canal, at the bottom of which it pierces the bone by minute openings, and is then distributed to the complicated chambers of the internal ear. The *portio dura* arises also from the medulla oblongata, passes, with the portio mollis, into the internal auditory meatus, and there communicates with it; but it then leaves that nerve and escapes by a special opening, the stylo-mastoid foramen, through the base of the skull, and emerges close to the inner side of the mastoid process. As it passes through the temporal bone, it presents a gangliform swelling, which is connected with two neighboring sympathetic cranial ganglia. It next descends outwards, behind the border of the lower jaw, running through and supplying the parotid gland, and then dividing into numerous branches (see Fig. 62), like the foot of a bird, hence named *pes anserinus* or goose's foot, ramifies over the face, and supplies all the facial muscles. It also supplies, partly, the muscles of the outer ear, and likewise one little muscle of the tympanum or middle ear, and gives off a remarkable branch, named the *chorda tympani*, which descends to the submaxillary salivary gland, and joins the gustatory nerve.

The *eighth* pair of nerves, 8, placed along the side of the medulla oblongata, consist of *three* portions, which are all given off from the gray matter within the posterior part of the medulla oblongata and spinal cord. The *first*, called the *glosso-pharyngeal* nerve, is the smallest and highest; it passes out through the base of the skull into the neck, and supplies chiefly, as its name implies, the mucous membrane of the tongue, and the lining membrane, and partly the muscles, of the pharynx; but it also sends branches to the tonsils, the palate and its muscles, and the Eustachian tube, and even to the tympanum or middle ear. The *second* or largest portion of the *eighth* pair, named the *pneumogastric nerve*, *par vagum*, or *vagus nerve*, leaves the sides of the medulla oblongata, passes through the base of the skull into the neck, and is distributed chiefly, as its first name indicates, to the lungs and stomach. It is called vagus, or the wandering nerve, from the great distance from the head, to which its branches extend. Besides the stomach and lungs, it moreover supplies branches to the muscles and lining membrane of the pharynx, to the lining membrane and muscles of the larynx, the lining membrane and muscular fibres of the windpipe, the mucous and muscular coats of the œsophagus, and, lastly, a most important portion of the nerve, cardiac branches, which go to the heart. The *third* division of the *eighth* pair, named the *spinal accessory* nerve, arises, by many funiculi, from the lateral columns of the spinal cord, low down in the neck, and therefore, from its origin, might be deemed a *spinal* nerve; but it ascends through the foramen magnum into the skull, receives additional roots from the sides of the medulla oblongata, and then passes out through the base of the skull, into the neck; here it communicates with the pneumogastric nerve, and then descends obliquely downwards, and supplies chiefly the sterno-mastoid, and trapezius muscles. The glosso-pharyngeal and pneumogastric nerves, have each ganglionic masses upon their trunks; the spinal accessory nerve has no such ganglion. The *ninth* pair of cranial nerves, 9, or *hypo-glossal* nerves, emerge from the front of the medulla oblongata, between the olivary body and the anterior pyramid, though their fibres arise deeply from gray matter at the back part of the medulla. The nerves pass forwards, out of the cranium, through special foramina in the occipital bone, and, entering the neck, run onwards, to be distributed chiefly to the muscles of the tongue. They also supply, however, most of the muscles in front of the neck. In some mammalia, this nerve has a small posterior sensory root, having a ganglion upon it, thus manifesting an affinity with the spinal nerves, next in succession to it, which we have immediately to describe.

Estimates have been made of the number of nerve fibres present in several of the cranial nerves. The numbers in the following nerves, which, as we shall hereafter see, are motor in function, are as follows: the third or oculo-motor, 15,000; the fourth or pathetic, 1100; the small root of the fifth, 9000 to 10,000; the sixth or abducent nerve, 2000 to 2500; the portio dura or facial, 4000 to 4500; the spinal accessory, 2000 to 2500; and the ninth or hypo-glossal, 4500 to 5000. Of the other nerves, the glosso-pharyngeal is said to contain 3500, and the pneumogastric 4000 small and 5000 larger nerve-fibres.

The *spinal nerves.*—The spinal nerves, arising from the spinal cord, consist of thirty-one pairs, Fig. 60, arranged into five groups, named, according to the vertebræ, between which they pass out from the spinal canal, the *cervical*, *dorsal*, *lumbar*, *sacral*, and *coccygeal* nerves. There are eight pairs of cervical nerves, twelve dorsal, five lumbar, five sacral, and one, sometimes two, coccygeal.

Each spinal nerve arises from the corresponding side of the spinal cord, by means of *two roots*, which consist of bundles, or funiculi, springing from the lateral furrows upon the cord. The deep paths of these roots within the cord, require to be carefully studied.

The funiculi which form the *posterior root*, larger and more numerous than those of the anterior root, arise from the posterior lateral furrow. Within the cord, they may be traced into, or through, the posterior white columns, whence they proceed either downwards, transversely, or upwards, forming three sets. The descending set pass obliquely downwards, through the gray matter, and even reach the anterior horn, whence they penetrate the anterior white columns, spreading upwards and downwards, many of them entering the anterior roots of the neighboring nerves, but some losing themselves in the anterior columns. The transverse set of fibres enter the posterior horn, crossing the gelatinous portion of this; some join the multipolar cells, others pass between them, either into the posterior or lateral columns; others cross through the transverse commissure of the cord, to reach the posterior and lateral columns of the opposite side, some being traceable, it is said, to the roots of the nerves; lastly, some end in a network reaching towards the anterior cornua. The ascending set are partly continuous with the fibres of the posterior columns, but most of them pass obliquely upwards through these columns, and enter the gray substance, where some appear to form loops, and return into the posterior columns.

The fibres of origin of the *anterior roots*, pass in distinct horizontal bundles, through the anterior columns, to the anterior horn of gray matter; thence they diverge in three directions, upwards, downwards, and horizontally. Many may be traced to the large multipolar cells of the anterior horn; some pass through into the anterior, and others into the lateral, white columns of the same side; others proceed through the anterior part of the commissure, and pass over to the opposite side into the anterior and lateral columns, and, it is said by some, even into the anterior roots of that side; many enter deeply into the cornua, and then diverge upwards, downwards, and inwards; the latter come into near proximity with the fibres of the posterior roots, and possibly pass into them.

On leaving the cord, the posterior funiculi are gathered into a single nerve root, upon which is found an oval mass of gray matter, situated usually in the intervertebral foramen, and called a *spinal ganglion*, or *ganglion* of the *posterior root* of a spinal nerve. The anterior funiculi, smaller and less regularly disposed, emerge in a similar manner from the anterior lateral furrow. The *anterior root*, formed by the gathering together of these funiculi, passes *over*, and *beyond*, the spinal ganglion of the posterior root, and then joins that root to form a single *trunk*, which, passing out from the intervertebral foramen at the side of the vertebral column, divides into anterior and posterior *branches*, which are distributed, the latter to the muscles and skin behind the spine, and the former to the muscles and integuments of the parts of the body in front of the spine, and to the limbs; the anterior branches are accordingly generally larger; moreover, they form *plexuses*, as will be presently mentioned, and they are all connected by branches with the sympathetic nerve.

The upper *cervical* nerves supply the deep and posterior muscles, and the skin of the neck and shoulder. From the anterior branches of the third and fourth cervical nerves, with a small fasciculus from the fifth, a most remarkable branch, called the *phrenic nerve*, runs down through the thorax, on the sides of the pericardium, and reaches the diaphragm, or partition between the thorax and abdomen, to the muscular fibres of which it is distributed. The lower cervical nerves which arise from the cervical enlargement of the cord, and are much larger than the upper cervical, are chiefly distributed by the large anterior branches, to the muscles, the skin, and other parts of the upper limbs, a few branches being furnished to the neck and trunk. The *dorsal* nerves give off, besides some small branches to the upper limb, the *intercostal* nerves, which supply the proper muscles of the thorax, namely, the intercostal muscles, the deep muscles of the back, the upper part of the muscles of the abdomen, and the skin over the corresponding parts of the trunk. The first dorsal nerve assists in supplying the upper limb. The *lumbar* nerves supply the lower part of the muscles of the back and abdomen, the muscles within the pelvis, and the muscles and skin of the lower part of the trunk, of the upper part of the thigh, and the skin of the inner side of the thigh and leg, down to the heel. The first lumbar nerve is sometimes joined by a branch from the last dorsal, whilst the fourth partly, and the fifth almost wholly, descends to join the large upper sacral nerves. The *sacral* nerves chiefly supply certain muscles of the pelvis, those of the back of the thigh, all those of the leg and foot, and the parts of the skin of the lower limb, not supplied from the nerve already mentioned. The two lower lumbar, and the three upper sacral, nerves arise from the lumbar enlargement, and are the largest of the spinal nerves, and indeed larger than any of the cranial nerves, being the largest nerves in the body. The *coccygeal nerves*, the smallest of the entire series, supply the parts adjacent to the coccyx.

The *roots* of the cervical nerves within the spinal canal, are short, arise at brief intervals from the sides of the cord, and pursue a nearly horizontal course to the interspaces, or places of exit, between the vertebræ; but, in the dorsal region, the roots of the spinal nerves are longer and more oblique; and, on arriving at the lumbar and sacral nerves, as the spinal cord itself terminates opposite the lower border of the first lumbar vertebra, the roots of the nerves spring in a crowded manner from the cord, and, descending in the vertebral canal, inclosed within the sheath of the cord, pursue a progressively longer and more vertical course, before they reach their respective intervertebral foramina of exit. The pointed lower portion of the spinal cord, together with the roots of the lumbar and sacral nerves descending from it, produce the appearance named the *cauda equina*, or horse's tail, Fig. 60, *e*.

On comparing the preceding description of the cranial with the spinal nerves, it will be noticed that all the spinal nerves arise by *two roots*, viz., a posterior ganglion-bearing root, and an anterior root having no ganglion, and joining the other root beyond its ganglion. Of the cranial nerves, however, the fifth nerve alone so far resembles a spinal nerve as to have a double root, one ganglionated and the other not; whilst the glosso-pharyngeal and pneumogastric have ganglia upon their trunks, and the remainder arise by single roots unprovided with ganglia. We shall hereafter return to the subject of the homology of the cranial with the spinal nerves.

Nervous plexuses.—In pursuing their course to the various tissues which they supply, the branches of the nerves, both cranial and spinal, always continue to divide and subdivide into smaller and smaller twigs, until they arrive at minute filaments, or even at single fibres, which terminate in various ways, in the tissues to which they are distributed (p. 53). At some parts of their course, certain branches of the nerves reunite again, so as to form angular *networks*, or meshes, called *plexuses.* Examples of these plexuses, are met with in certain junctions, or anastomoses, of the fifth and facial nerves on the face, and in the union of the pharyngeal branches of the glosso-pharyngeal and pneumogastric nerves. Smaller meshes of anastomosis, or junctions, occur in the branches of the same nerve, as in those of the olfactory nerves beneath the nasal mucous membrane, and in the still more microscopic interweaving of the fibres of the optic nerve in the retina, and of the auditory nerve in certain parts of the internal ear. But very large and remarkable plexuses are formed by the anterior branches of the spinal nerves. Thus, the *cervical plexuses* are formed between the first four cervical nerves, at each side of the neck; the so-called *brachial* or *axillary plexuses*, Fig. 60, *ax*, are composed of branches of the four lower cervical and first dorsal nerve, at the root of the neck, and give off the large nerves of the upper limb, Fig. 62; the *lumbar plexuses*, Fig. 60, *l*, are formed by the four upper lumbar nerves; and, finally, the *great sacral plexuses*, *s*, are formed by the last two lumbar and four upper sacral nerves, from which the very large nerves of the lower limb proceed, amongst them the great *sciatic nerve*, the largest nerve in the body. In these plexuses, there is an interchange not only of the funiculi or bundles of nerve fibres, but necessarily of the nerve fibres themselves, belonging to various cranial or spinal nerves. The nerve fibres may pass, from one nerve entering the plexus, into all the nerves given off from it, and this in various degrees of intermixture; these fibres themselves, however, never divide and unite, but retain their continuity from the brain, or cord, to the localities of their ultimate distribution. The effect of these plexuses is, that any given nerve beyond the plexus, contains, or is composed of, nerve fibres springing from a considerable length of the spinal cord, and thus their purpose seem to be—*first*, to establish a connection between any one point of local distribution and a large extent of the nervous centres; and, *secondly*, to connect many points of local distribution with some given portion of the nervous centres. Thus, muscles supplied through such a plexus, are brought into physiological relation with various portions of the cord. In the same manner, nerve fibres having different endowments, sensory, motor, or reflex, are hereby intermixed; and, moreover, fibres possessing the same endowments, are more widely distributed.

The Sympathetic Nervous System.

The *sympathetic nervous system* consists of two knotted *ganglionated nervous cords*, which are placed one on each side of the vertebral column, in the neck, in the thorax, in the abdomen, and in the pelvis, Fig. 62. These cords are connected with certain other ganglia situated deeply between the bones of the cranium and the face, and also with certain important interlacements, or *sympathetic plexuses*, and ganglia, placed on, or near, the great viscera in the chest and abdomen, and named the *prevertebral sympathetic plexuses*. By many authorities, the ganglia connected with the trunks or roots of certain cranial nerves, and those situated upon the posterior roots of the spinal nerves, are regarded as belonging to the sympathetic system.

The *ganglia* of the sympathetic are fewest and largest in the neck, there being only three, instead of a number equal to that of the cervical nerves: perhaps a process of fusion here takes place. The *superior cervical* ganglion measures at least $1\frac{1}{4}$ inch in length; there are also a middle and lower cervical ganglion, the former being sometimes absent. The *dorsal* ganglia are more regular, being usually twelve in number, and of more moderate size. The *lumbar* and *sacral* ganglia become still smaller, and lie in front of the bodies of the vertebræ, instead of at the sides. Lastly, the ganglionated cords of the two sides, terminate below in a single coccygeal ganglion, placed on the front of the coccyx. Each of these ganglia, from the neck to the pelvis, is connected with the adjacent spinal nerve, as those in the cranium and face are with the cranial nerves, by one, or generally two, short nervous cords proceeding outwards; besides this, each is, of course, connected with the ganglia above and below it, by the main trunk of the sympathetic itself; finally, each gives off a branch inwards to the so-called *prevertebral* plexuses.

From the superior cervical ganglion of the sympathetic, branches ascend to the base of the skull, and form direct, or indirect, communications with certain cranial nerves; as, for example, with the third, sixth, facial or portio dura of the seventh, and particularly with the fifth nerves. It is with these branches, also, that the small sympathetic ganglia, found in the spaces between the cranial and facial bones, are connected, viz., the *lenticular* ganglion in the orbit, the *otic* ganglion and the *spheno-palatine* ganglion behind the nasal cavities, and the *submaxillary* ganglion situated on the submaxillary salivary gland; all four ganglia are connected with branches of the fifth cranial nerve.

Of the prevertebral plexuses of the sympathetic, the chief are the *cardiac*, the *solar*, and the *hypogastric;* but there are several secondary plexuses, such as the *laryngeal*, *pharyngeal*, the *pulmonary*, the *renal*, and others. The cardiac plexus is derived from the descending cardiac branches of the cervical sympathetic ganglion, mixed with branches of the pneumogastric; the great solar plexus is situated in the abdomen,

Fig. 62

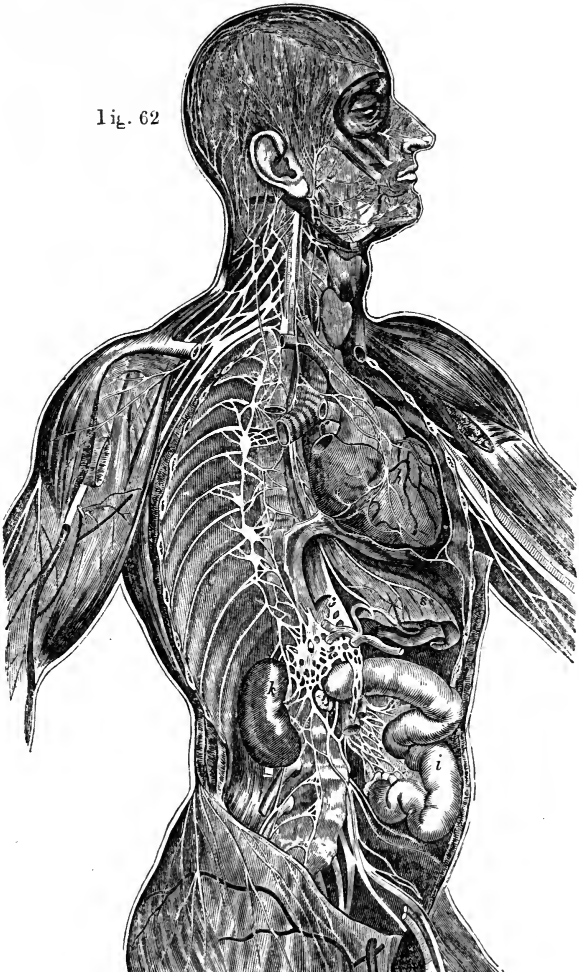


Fig. 62. The nerves. On the face and head, are branches of the facial, trigeminal, and cervical nerves. In the neck, are the cervical and brachial plexuses and nerves. In the thorax, abdomen, and pelvis, is seen the right sympathetic nerve, consisting of a ganglionated cord connected with the intercostal nerves, and giving off branches in front, to the prevertebral plexuses, which supply the viscera, *e.g.*, the heart, *h*, the stomach, *s*. the intestines, *i*, and the kidney, *k*, near which is seen the solar plexus. The lumbar plexus is seen in the pelvis.

in front of the aorta, and is derived from the three *splanchnic* nerves proceeding from the lower six thoracic ganglia, and from branches given off from the gray matter of a large sympathetic ganglion, named the *solar ganglion;* it is joined also by a few terminal branches of the pneumogastric nerves. The renal plexuses are derived partly from the solar plexus, and partly from the lowest splanchnic nerves; and lower down, are the hypogastric plexuses and their offsets.

The branches proceeding from the various sympathetic ganglia and plexuses, are thus distributed. The *lenticular* ganglion receives fibres from the third, sixth, and fifth cranial nerves, and supplies branches to the eyeball, especially destined for the iris, and for the bloodvessels, including those of the ciliary processes. The *otic* ganglion, connected with the fifth and glosso-pharyngeal nerves, gives branches to a muscle in the tympanum or middle ear, and thus probably assists in the control of parts of the organ of hearing. The *spheno-palatine* ganglion is connected with branches of the fifth and the facial nerves; its branches may be traced to the mucous membrane of the nose and palate, so that it may be considered as associated with the parts concerned in the functions of taste and smell. The *submaxillary* ganglion, which communicates with the fifth and facial nerves, sends its branches chiefly to the submaxillary gland. The Gasserian ganglion on the root of the fifth pair, also the ganglia on the trunks of the glosso-pharyngeal and pneumogastric nerves, and, lastly, those found on the posterior roots of the spinal nerves, if these be really sympathetic ganglia, as seems probable, must supply sympathetic nerve fibres, which are blended with the fibres of the nerves on which they are respectively placed, and are most likely distributed with them to various parts of the body.

Of the chief plexuses, the cardiac sends branches to the heart, Fig. 60, *h*, and to the great bloodvessels, and from these, others are continued on to the roots of the lungs, assisting in the formation of the pulmonary plexuses. From the aorta, the sympathetic nerves are continued on to the great arteries, and so on to all the arteries of every part of the body. From the solar plexus, proceed the branches to the stomach, *s*, intestines, *i*, liver, kidneys, *k*, and other abdominal viscera; each organ having a secondary plexus named accordingly. The hypogastric plexus supplies the pelvic viscera and their bloodvessels.

The ganglia of the sympathetic nerves are its proper centres; they consist of colored nerve cells, mostly, it is said, unipolar, or provided with only one process; they give origin to the proper sympathetic nerve-fibres, which are nearly all of the gelatinous, or non-medullated, kind (p. 52). But the cords which connect the trunks of the sympathetic with the several cranial and spinal nerves, are whitish in color, whiter even than the branches given off from the sympathetic to its plexuses; whilst the ultimate ramifications on the arteries are of a pale pinkish hue. These last ramifications, which, as just mentioned, are commonly supported upon the small arteries of the different parts toward which they run, are composed of a few tubular fibres, mixed with many of the non-medullated kind. They are often connected with, and reinforced by, numerous additional minute ganglia: this is especially the case in regard to the arteries of the viscera. In the limbs, sympathetic nerve-fibres are probably blended with the cerebro-spinal nerves. The final destination of the sympathetic nerve-fibres, whether medullated or non-medullated, is not well known; but it is supposed that they end, in part at least, in the muscular coat of the small arteries. Even in the substance of certain organs, as for example, in the heart and lung, innumerable minute visceral sympathetic ganglia are met with; and beneath the mucous membrane of the alimentary canal, microscopic structures, resembling gray nerve-cells, are also found, and are supposed to belong to the sympathetic system.

On examining the course of the fibres forming the connecting cords between the trunk of the sympathetic and the cranial and spinal nerves, which are sometimes regarded as the *roots* of the sympathetic system, it is found that they consist of two sets of fibres, passing each from one system to the other: the cerebro-spinal white medullated fibres pass through the ganglia of the sympathetic, and so onwards into the longitudinal cords which form the trunks of the sympathetic nerve, and thence into the branches given off to the prevertebral plexuses; the proper sympathetic fibres, always small and usually non-medullated, pass to the anterior branches of the corresponding spinal nerve. The posterior roots receive fibres from their own spinal ganglion. From these facts, it follows that the fibres of the cerebro-spinal and sympathetic systems are here intermingled; it is also apparent why the branches of the sympathetic nerves, although more or less white in the first part of their course, become more pinkish as they get nearer to their distribution. As all the sympathetic nerves probably contain a few fibres derived from the cerebro-spinal axis, so all the cranial and spinal nerves probably contain, in their branches of distribution, some sympathetic nervous fibres. It must further be concluded that the sympathetic nervous system is not to be regarded as a mere offset from the cerebro-spinal system, nor yet entirely independent of it; but rather that it is a *special* nervous apparatus, having numerous gray nervous centres of its own, though intimately connected with, and therefore influenced by, the cerebro-spinal system.

FUNCTIONS OF DIFFERENT PARTS OF THE NERVOUS SYSTEM.

The nerves, whether cerebro-spinal or sympathetic, being composed entirely of nerve fibres, either white or gelatinous, are considered to act merely as *conductors* of impressions, or of the effects of impressions. The white parts of the substance of the spinal cord, the medulla oblongata, the pons Varolii, the cerebral peduncles and hemispheres, and the cerebellum, must also likewise be limited, functionally, to conducting properties. The gray matter of the sympathetic ganglia, and of the several parts of the cerebro-spinal axis, must not only conduct, but also reflect, diffuse, and transfer impressions, and must even originate changes which stimulate the excitability of the nerve-fibres. The ganglionic masses, whether of the cerebro-spinal or sympathetic system, are therefore said to be *centres of activity*. The connections of the gray matter, and its greater relative vascularity, are conditions which also favor this view. For the continued activity of both the white and gray matter, it is necessary that they should be adequately supplied with healthy arterial blood, and be maintained within the limits of a certain range of temperature. Imperfectly oxygenated, or imperfectly decarbonized blood, or blood impaired or impoverished, or poisoned by the natural secretions of the body, or by foreign substances introduced into it, is unfit for the healthy nutrition of all parts of the nervous system, and more or less interferes with, or may altogether arrest, their functions. The temperature at which the nervous system can act properly, differs in the warm- and cold-blooded animals; it is presumable that, in all cases, the natural temperature of the blood of the animal, is that best fitted for the functional activity of the nervous system. A warm-blooded animal, it has been shown, cannot long survive at a temperature lower than 72°, nor yet above 120°. The benumbing effects of cold on our sensations, and its ultimate fatal results, are well known, and will be hereafter explained.

Functions of the Cerebro-spinal Nerves.

That the nerves are concerned in the functions of sensation and motion, is suggested by the facts, that they are very numerous in all highly sensitive parts, such as the eye, the tongue, and the cutis, or true skin, and are also abundant in the muscles, that they are few in number in the slightly sensitive and non-contractile tissues, such as the ligaments, tendons, and bones, the latter of which have been said to be absolutely insensible in health, and, lastly, that they are entirely absent in the insensible tissues such as cartilage, the cuticle, and the nails. The results of accidental destruction or division of a nerve in the human body, and of its section in experiments upon living animals, afford direct proof of the function of these parts; for when a nerve, the branches of which are distributed to a sensitive part, such as the eye or a portion of the hand, is destroyed by disease, or divided by injury, or in an experiment, the sensibility, general or special, of that part is destroyed; and so also, when a nerve proceeding to certain muscles is cut accidentally or intentionally, those muscles are paralyzed. If in a frog, the bone and all the soft parts of the thigh, with the exception of the nerves, be cut through, sensibility and power of motion are still manifested, in various ways, in the parts so partially isolated from the body; but, on the other hand, if the nerves themselves be divided, the other tissues remaining uncut, sensibility and motion are destroyed in the parts previously supplied by the cut nerves. Tight ligature of the nerves produces the same loss of sensation and power of movement in the parts below the seat of ligature. There can be no doubt, therefore, that the nerves are concerned in the production of the phenomena of sensation and motion.

If the upper part or end of a divided spinal nerve, which is still in connection with the cord and brain, be pinched or irritated in any way, a sensation, that of pain, is produced; again, if the lower portion, which is severed from the spinal cord, be pinched or irritated, no sensation is felt, but the muscles supplied by the nerve undergo contraction. In these experiments, it is inferred that the upper part of the nerve, being stimulated, conducts the effects of that impression up to the nervous centres, and that the lower part of the nerve conducts those effects downwards to the muscle. Hence the special office which the nerves perform in the phenomena of sensation and motion, is said to be that of acting as conductors. Certain structural arrangements in the nerves and the nerve fibres, have been supposed to favor and render more precise this conducting power, by insulating the channels of conduction; thus, the axis fibre being supposed to be the conducting substance, the medullary sheath and the tubular envelope of the white fibres, are said to act as insulators. In the nerves, the sheath or neurilemma may serve as an additional insulating as well as a protecting investment. No matter how close to the spinal cord the nerves are cut, similar results to those just mentioned ensue, the portion of the nerve detached from the cord never being capable of producing any sensory phenomenon, nor yet being able, if left unirritated, to determine any regular movement in the muscles with which it is still connected. Hence we arrive at the negative conclusion, that the nerves of themselves are not either seats of sensation, or natural centres of origin of motorial stimulus. It has already been stated that the fibres of a spinal nerve, which convey the sensory impressions upwards, are called the *afferent* nerve fibres; whilst those which conduct the effects of motorial stimuli downwards, are named *efferent* fibres.

In the trunks of all spinal nerves, these two kinds of fibres are intermixed; but at the roots of the nerves, it has been discovered, as the result of experiment, that these two kinds of fibres are separated; and that, whilst the afferent or sensory fibres pass entirely through the posterior ganglion-bearing root up to the cord, the efferent or motor fibres pass from the cord exclusively through the anterior roots. This remarkable natural separation or analysis of the two sets of fibres, was discovered by our countryman, Sir Charles Bell, and forms the basis of his, and of still later, discoveries in the functions of the nervous system.* The doctrine of Sir Charles Bell is demonstrated by the following experiments. If the anterior root only of a spinal nerve be cut across, sensation in the part below remains unaltered, but the muscles are paralyzed, or the power of movement is lost. If the posterior sensory root only be divided, sensation is lost in the parts below, but voluntary power remains. If both roots are divided, sensation and motion are both destroyed. Again, if the lower or distal portion of the divided posterior root be irritated, no signs of pain or other sensation, and no motions take place in the parts below; but if

* Experiments made on the various parts of the nervous system in living animals, have led to the formation of the most important inferences as to the respective uses of these parts, whether composed of white or gray nervous matter. Sections of various kinds, and stimulation before or after such sections, have, indeed, been the chief methods employed in the investigation of the intricate problems of nervous action. Very numerous instances will have to be mentioned in the following pages. Whilst we may designate as cruel and profitless, the mere repetition of well-known experiments upon living animals, with the exception of a few of fundamental importance, we must seriously maintain the right of the physiologist to employ, and the propriety of employing, the lower animals in well-considered experiments for the elucidation of those laws of life, which our intelligence prompts us to explore, and on a knowledge of which the alleviation of human suffering so largely depends.

the upper or proximal end be irritated, evidences of pain ensue; where as, if the distal portion of the divided anterior root be irritated, movements occur in the muscles below, without manifestations of sensation; but if the proximal portion be irritated, no movements in those muscles take place. Sometimes, however, irritation of the distal cut portion of the anterior roots produces slight evidences of pain, formerly spoken of as the result of *recurrent sensibility*, and referred to the existence of a few recurrent afferent fibres which pass from the anterior root upwards along the posterior root to the cord. The pain which follows irritation of the distal cut end of the anterior root, has also been attributed to the excited cramps or movements being themselves the cause of pain, by inducing irritation in the sensory fibres of the muscles. Certain slight movements produced by irritation of the posterior roots are due to reflex action.

Additional evidence of the properties of the two roots, is furnished by an experiment in which the anterior roots of the three spinal nerves which supply the hind leg of a frog, are divided on the left side; whilst the posterior roots of the corresponding nerves, are divided on the right side. On then pinching or cutting the left leg, or even *cutting it through*, evidence of pain is given by the frog, in energetic motions of every part of the body, excepting those of the limb itself; whereas, if the right leg be pinched or cut, or even *cut through*, no evidence of pain follows, and no decided motion, excepting the twitching of the muscles that happen to be divided. From these and the preceding experiments, it becomes evident that the posterior roots of the spinal nerves contain the afferent fibres, and convey the effects of sensory impressions inwards to the cord; whilst the anterior roots contain efferent fibres, and convey the effects of motorial stimuli to the muscles. In the trunks and principal branches of the nerves, both sets of fibres are usually intermixed. Hence, if a mixed nerve be ligatured at two points, irritation between the ligatures produces no effect; but if the lower ligature be relaxed, such irritation produces movements in the muscles to which the branches of the nerve are distributed; whilst, if the upper ligature be loosened, pain ensues on like irritation. In the purely sensory branches of the mixed cranial or spinal nerves, as, for example, in those distributed to the mucous membrane of the tongue, and to the skin of the tips of the fingers, only afferent fibres exist; whilst in the proper muscular branches, the fibres are chiefly efferent, though doubtless a few afferent fibres are intermingled, for the purpose of conveying upwards to the nervous centres, the effects of the special sensory impressions produced by the condition of the muscle itself. It is through the spinal nerves that the contraction of the muscles of the trunk and limbs is excited; by them also, those muscles are endowed with their special, though slight, sensibility, are able to produce the muscular sense, the feelings of fatigue or cramp, and to transmit impressions by which we recognize resistance or weight. The spinal nerves likewise are the channels of sensation for the skin and other soft parts of the trunk, limbs, and back-part of the head.

The functions of particular nerves are determined, partly by their ultimate distribution, but also by experiments on animals, and observations made in cases of injury or disease in man. In this way, the properties of the several cranial nerves have been determined, and the nerves themselves have been classified accordingly. Thus, the olfactory, the optic, and the portio mollis of the seventh pair, or auditory nerve, are purely and specially sensory, and contain afferent fibres only; the third pair, oculo-motor, or motor nerves of the eye, the fourth pair, trochlear, or pathetic nerves, the sixth pair, or abducent nerves, the portio dura of the seventh pair, or facial nerve of each side, and the ninth pair, or hypoglossal nerves, are purely motor nerves, and contain efferent fibres only; whilst, lastly, the fifth pair and the eighth pair, its three divisions being considered as one nerve, are, like the spinal nerves, mixed sensory and motor. The fifth nerve arises, indeed, as we have seen, like the spinal nerves, by two roots, of which the larger one is sensory, partly serving for common sensation, and partly, it is believed, for the gustatory sense, whilst the smaller one is motor. The glosso-pharyngeal division of the eighth pair is sensory, partly tactile, and partly gustatory; the spinal accessory division is chiefly motor, containing a few sensory fibres derived from the pneumogastric, whilst the great pneumogastric itself is partly motor, and partly sensory, some of its terminal branches being sensory, and others motor.

The following table shows briefly these relations:

CRANIAL NERVES.

First Group.—Sensory, . . .	First, or olfactory. Second, or optic. Auditory (portio mollis of seventh).
Second Group.—Motor, . . .	Third nerve (motor of eye). Fourth nerve (pathetic). Sixth nerve (abducent). Facial (portio dura of seventh). Ninth nerve (hypoglossal).
Third Group.—Mixed Nerves,	Fifth nerve (trigeminal). Eighth nerve (including its three divisions).

The *special* functions of these nerves are as follows: The *olfactory*, *optic*, and *auditory* nerves appear to have special endowments, or to react only under the effects of peculiar stimuli, producing odorous, luminous, or sonorous impressions; for no other sensations can be produced by their irritation. Thus, pinching, or the electric stimulus, does not cause pain, but the sensation of light or noise, if applied to the optic or auditory nerves. Pain may, however, be produced by an excess of their proper stimuli, as by intense light and very loud noise. Their division destroys the function of the sensory organs to which they are distributed. It has not been proved that an ordinary stimulus applied to the olfactory nerves, produces smell. Further details on these subjects will be given in the Chapter on the Senses.

The third cranial or *oculo-motor* nerve, governs all the muscles of the eyeball, except the external rectus and the superior oblique muscle; through its connection with the lenticular ganglion, it effects the contraction of the pupil, exciting the circular fibres of the iris. This result also follows experimental irritation of the nerve, whilst its division causes dilatation of the pupil by paralyzing its circular fibres. It may act as a voluntary nerve, or in the so-called reflex manner, being then excited through the optic nerve. It contains a few sensory fibres, probably derived from communications with the fifth cranial nerve.

The fourth or *pathetic* nerve supplies the superior oblique or trochlear muscle of the eyeball, with motor fibres, which may act voluntarily, or in a reflex manner; it also contains a few sensory fibres.

The fifth or *trigeminal* nerve is a mixed nerve, through which all the parts mentioned in the description of its branches (pp. 250–51) are endowed with sensibility, and through which the movements of the muscles of mastication are effected. Division of this nerve on both sides, within the cranium of a rabbit, destroys the sensibility and mobility of these parts; and the head is carried as if it were a foreign body. Division on one side, paralyzes the same parts on one side only. Moreover, in a short time, the cornea becomes opaque, or even ulcerated, and the humors escape. These results have been referred to an interruption of the nutrition of the eye, caused by the arrest of the influence of the fifth nerve, exercised through its connections with the lenticular sympathetic ganglion; but, as the inflammation ceases, when the eye is covered by fixing the animal's ear over it, it may be that they are due to the cessation of the proper protective secretion and reflex movements of the eyelids. In the rabbit, contraction of the pupil follows both division and irritation of the fifth nerve; the former, because the radial fibres of the iris, which are supplied by this nerve through the lenticular ganglion, are paralyzed; the latter, because some fibres from the sixth cranial nerve pass by the ganglion, and proceed at once to the iris; in the dog, cat, and pigeon, these effects do not ensue. The nasal mucous membrane becomes congested and bleeds easily, and the sense of smell is diminished; common sensibility, and the sense of taste at the tip of the tongue, are also affected, thus apparently indicating that the lingual branch of the fifth nerve is a gustatory nerve. The connection of the auriculo-temporal branch of this nerve with the parotid gland, and of the inferior maxillary branch, through the submaxillary and sublingual ganglia, with the submaxillary and sublingual glands, is of great importance as regards the functions of those glands; for division of the fifth nerve causes a diminution, and irritation of the nerve, a copious increase of their secretion. This is explained by the fact that irritation of the fifth nerve (and also of the facial), causes a dilatation of the nutrient vessels of the glands, and so great an increase of their activity, that they secrete an abundant but thin fluid. On the contrary, irritation of the sympathetic nerve-fibres, causes contraction of those vessels, and is followed by a scanty but much more viscid secretion.

The sixth or *abducent* nerve is exclusively concerned in the government of the external rectus muscle of the eye, which turns the eyeball outwards.

The *portio dura* of the seventh nerve, or the *facial* nerve, is a purely motor and secretory nerve, any sensory fibres which it contains, being derived from its communications with the fifth and the pneumogastric nerves. Its division, or injury, is accompanied by paralysis of all the muscles of the face, excepting those supplied by the fifth nerve, *i. e.*, the masticatory muscles. In these cases, the mouth is distorted, being drawn over to the opposite side by the unparalyzed muscles; the act of blowing out a candle is awkwardly performed, and is accompanied by a puffing-out of the loose and paralyzed cheek; whistling is impossible, and the attempt to smile causes a ludicrous expression; moreover, the eyelids cannot be closed, nor the skin of the forehead thrown into wrinkles on the paralyzed side. The influence of this nerve on the flow of the saliva has just been mentioned. In paralysis of the orbicular muscle, which serves to close the eyelids in winking, the movements of the eyeball itself are an imperfect substitute for the action of the lids, in keeping the mucous membrane clean and moist, and in directing the superfluous tears into the lachrymal passages; hence these escape over the cheek, and the mucous membrane of the eyeball becomes inflamed.

The *glosso-pharyngeal* nerve is chiefly an afferent nerve, being the channel of sensation for the parts to which it is distributed. Some of its fibres have the special power of conducting gustatory impressions, viz., the branches which supply the root and sides of the tongue; it is generally believed to be the nerve concerned in conveying disagreeable gustatory impressions to the medulla, and has been jocularly named the disgustatory nerve. A few of its fibres are motor, viz., those which supply certain palatal muscles.

The *vagus* or pneumogastric nerve is a mixed afferent and efferent nerve from its very origin, and does not, as some have supposed, derive all its motor fibres from the spinal accessory nerve; for irritation of the pneumogastric within the cranium, before it communicates with other nerves, causes contraction of the muscular fibres of the pharynx, of the intrinsic muscles of the larynx, and of the fibres of the œsophagus and stomach. It is a sensory, motor, and important excito-motor nerve. The sensations of pain, oppression, irritation of the air-passages, want of air, hunger, thirst, and satiety, are dependent on this nerve. It has a regulating influence over the functions of deglutition, digestion, circulation, and respiration. Division of one nerve in the neck, causes difficulty of breathing, and interferes with the digestive process. Division of both nerves is fatal, after a few hours or days, in consequence of asphyxia. These results indicate, generally, the office of this important nerve, which, however, is already joined, in the neck, by branches from the glosso-pharyngeal, spinal accessory, and hypoglossal nerves. After division of the right and left nerves, the sensibility of the larynx and trachea disappears, and the reflex movements, excited through them, such as coughing, cease. Owing to paralysis of the laryngeal muscles, the vocal cords are relaxed, and the voice is rendered hoarse and feeble, or entirely fails. The inspirations are retarded, and an embarrassment of breathing is produced, ending in suffocation; this occurs more quickly in young animals, owing to the want of development of the cartilaginous structures, and the more yielding character of all the parts, so that the inter-arytenoid portion of the glottis is more easily closed. The lungs exhibit congestions, extravasations of blood, and infiltration with serous fluid; the bronchial tubes become filled with mucus, so as to prevent the passage of air and the interchange of gases, the result being a gradual asphyxia. Irritation of the central portion of the divided vagus nerve, in the neck, produces acceleration of the movements of the inspiratory muscles, for example, of the diaphragm and external intercostals. The lower part of the œsophagus is paralyzed by division of both vagi in the neck; deglutition is impossible; the food is arrested in its descent, and is vomited, and if again swallowed is once more ejected; the movements of the stomach are also arrested; the food now stationary is only digested on its surface; the secretion of the gastric juice is merely diminished, not arrested; absorption continues uninterrupted. It would, appear, furthermore, that the vagus has a certain influence on the movements of the small and large intestines. Division of both nerves accelerates the action of the heart; irritation of the distal portion of the divided nerve diminishes, or even arrests, it. Section of these nerves arrests the formation of sugar in the liver; this process, however, is resumed on irritation of either of the cut ends of the nerve; the effect, in the case of irritation of the central end, is propagated through the nervous centres, and thence to the sympathetic nerve.

In a beheaded criminal, fifteen minutes after execution, it was found that the auricular contractions of the heart, which were still 60 to 70 per minute, were suddenly stopped by electrical shocks applied to the left pneumogastric nerve, the auricle remaining distended; electrical stimulation of the sympathetic, re-excited the movements. Hence it has been supposed that the vagus exercises an inhibitory action, rhythmically with respect to the sympathetic; but weak electrical currents applied to the former nerve itself, rather quicken the heart's action.

The *spinal accessory* nerve is not merely a motor root belonging to the pneumogastric, although it communicates motor fibres to that nerve; for it contains itself some sensory fibres. The exposure of this nerve by opening the cranium, is so speedily fatal to an animal, that experiments, for the purpose of determining its function, have been made by tearing out the nerve. This does not impair any of the movements which are regulated through the pneumogastric nerve, such as the respiratory movements; but swallowing is interfered with, and when both nerves are torn out, the voice ceases, the animal emitting only a bubbling noise. Extirpation of one accessory nerve causes hoarseness. Thus it appears that the spinal accessory nerves govern the momentary and voluntary opening or closure of the glottis, and the tension of the vocal cords necessary for the production of voice, or for the exercise of general muscular effort; whilst the respiratory movements of the glottis are under the control of the pneumogastrics. Deglutition is merely rendered difficult, because the pharyngeal and œsophageal branches of the glosso-pharyngeal and vagus are still in operation. Irritation of the roots of this nerve produces contractions in the œsophagus, pharynx, and larynx, as well as in the trapezius and sterno-mastoid; but if the roots of the vagus are first divided, only the two last-named muscles contract. This is explained by supposing that in the former case the movements are reflex, and excited through afferent fibres contained in the spinal accessory, which convey the stimulus to the medulla oblongata, and thence along the vagus nerve. Section of the muscular branches of the spinal accessory, only partially paralyzes the trapezius and the sterno-mastoid, because both these muscles also receive branches from spinal nerves.

The ninth, last cranial, or *hypoglossal* nerve, is purely motor, receiving, however, a few sensory fibres from the lingual branch of the fifth, the vagus, and some of the cervical nerves. Pinching or galvanizing the nerve, at its point of exit from the cranium, causes violent movements in the whole tongue; section of the nerves paralyzes the muscles of the tongue, without affecting either the common sensibility or the gustatory sense. Irritation of the distal portion of the divided nerve excites contractions in all the lingual muscles; whilst irritation of the central portion still connected with the medulla oblongata, induces signs of pain, owing to the admixture of sensory fibres from other nerves, as above mentioned, external to the cranium. When one hypoglossal nerve only, or its centre of origin, is affected by disease, the tongue is paralyzed on that side only, and when protruded, the tip is generally turned towards the side on which the muscles are paralyzed. Besides this, one proper muscle of the larynx, and certain muscles of the neck which are connected with that organ, are paralyzed by section of this nerve, which, therefore, serves not only to control the tongue, but also to adjust the larynx in speech.

Deep Connections of the Nerves and Centres of Sensation.—On tracing the roots of the several cranial nerves into the parts of the encephalon from which they appear to spring, it is found that they all have their origin in certain masses of gray matter, which accordingly are regarded as their proper ganglionic centres, and, in the case of the special sensory nerves, are believed to be endowed with modified forms of excitability or sensibility. The so-named ganglia of origin of the nerves of special sense, are very distinct, viz., the olfactory lobes, the optic lobes, and the auditory and gustatory masses of gray matter at the back of the medulla oblongata; whilst the nerves of common sensation and motion, cranial or spinal, arise from masses of gray matter, all situated below the optic thalami and corpora striata. It will be found, moreover, that the sensory nerves, or their sensory roots, originate from gray matter placed at the back of the medulla, in the course of the great sensory tract of white fibres, and in a line with the posterior portion of the gray matter, and the posterior columns of the cord; whilst the motor nerves, or their motor roots, spring from other masses of gray matter, associated with the great anterior or motor tracts, which pass down from the cerebral peduncles to the anterior and lateral columns of the medulla and cord. But the sensory ganglionic centres of the fifth nerves disappear altogether opposite the pons, so that the two motor nerves above this point, viz., the third and fourth, arise from gray matter placed close to the back of the upper part of the cerebral peduncles, near the floor of the fourth ventricle, the third being higher up, some of its fibres being even connected with the corpora quadrigemina. Below the sensory ganglion of the fifth, is that of the glosso-pharyngeal, the two masses touching and blending, and suggesting an explanation of the common gustatory function of certain branches of these two nerves; below this, is the sensory ganglion of the vagus, which lies immediately above the upper end of the posterior gray matter of the cord. In front of these sensory ganglia, and nearer the centre of the medulla, are the ganglia of origin of the motor cranial nerves; that of the motor root of the fifth being found opposite the upper part of the medulla, in close proximity with that of the sixth, and the portio dura or motor part of the seventh, which lie below and a little behind it; whilst the ganglia of the hypoglossal and spinal accessory nerves are found a little lower down, nearer to the centre of the medulla, and above, and in a line with, the anterior gray masses of the spinal cord.

Each of these ganglionic centres, is independent as to its proper functions, as may be shown, in some cases, by artificial sections, or by the effects of disease; but, during life, they are all associated, and are subordinated to the action of the cerebrum.

On comparing the cranial nerves with a typical spinal nerve, certain homologies are evident. The sensory portion of the fifth pair, together with the motor nerves of the orbit, viz., the third, fourth, and sixth nerves, and, lastly, its own motor portion, constitute a compound cranial nerve, homologous with a spinal nerve; the glosso-pharyngeal with the facial constitute a second; and the pneumogastric and spinal accessory form a third compound nerve, like a spinal nerve; the hypoglossal is, according to this view, supposed to be a spinal nerve, sometimes having in certain animals, as already mentioned, a small sensory root. The three complete compound cranial nerves just described, pass out of the cranium *between* its component segments, as the spinal nerves emerge through the intervertebral foramina. Of the nerves of special sense, the olfactory, optic, and auditory penetrate certain cranial elements, passing respectively *through*, or into, the ethmoid, sphenoid, and temporal bones. The optic and olfactory tracts are, indeed, not nerves, but processes of the cerebrum.

Functions of the Spinal Cord.

The functions of the spinal cord have, in the first place, to be considered in reference to sensation and to voluntary motion; and afterwards, in regard to the regulation of those peculiar movements, which constitute the so-called reflex action.

As regards *sensation*, the spinal cord, like the nerves, is only a *conductor* of the effects of sensory impressions; for, when it is divided, compressed, or otherwise injured or diseased at any part of its course, even up to the medulla, all the parts, supplied by nerves arising from it below the seat of injury, lose their sensibility, no pain being produced by pinching or otherwise irritating them. Neither is the cord itself sensitive; for, when it is divided, irritation of its lower portion produces no pain; but irritation of the upper portion of the cord, still in connection with the cerebrum, is followed by pain. The absence of pain, on irritating the lower portion which is severed from the brain, is held by most physiologists to be a sufficient proof that the cord itself is not sensitive, but that it is a mere conductor of the effects of sensory impressions. By a few others it is maintained, however, that when the cord is entire, as in its natural state, it really does possess true sensibility; but that, when divided, its sensations are not consciously felt, because they cannot produce any effect in the cerebrum from which the cord is severed. Seeing that the latter opinion is one which, in the nature of things, cannot be proved, for unless a sensation be consciously felt, it cannot be positively known to exist, it seems difficult to understand on what experimental grounds such an opinion can be supported; but we shall immediately have to consider certain phenomena, which have been supposed to justify such a view.

Secondly, as regards *voluntary motion*, experiments, or accidental injuries or disease, illustrate the fact that, in this case also, the cord is a mere conductor of the effects of the voluntary motorial stimuli, and is not a centre of origin of such stimuli; for all the parts below a division, injury, or disease of any portion of the cord, are completely paralyzed, or beyond the least control of the will. Severe as such an injury may be supposed to be, union of the divided cord, with complete restoration of its functions, has been observed in animals experimented upon, and, to a certain extent, in cases of injury or disease in man.

The true *sensorium*, or the seat of the realization of sensations, and so also the true seat or centre of *volition*, are situated higher up in the cerebro-spinal nervous centres, indeed, somewhere in the cerebrum itself. The effects of sensorial impressions and volitional stimuli, pass up or down along the cord, to or from those chief centres.

We have next to examine, what are the *paths* within the cord, which these two sets of impressions pursue; in briefer phraseology, what are the *paths of sensation*, and what are the *paths of motion*, through the cord. The gradual increase in quantity of the white matter of the cord, from below upwards, favors the idea, that its longitudinal columns are channels of conduction between the spinal nerves and the cerebrum; but the structure of these columns is very intricate, and the gray matter, as well as the white, would seem to possess a certain conducting power for sensory impressions. The minute details of the arrangement of the fibres in the spinal cord, have been studied, by making sections of hardened cords, and then examining them under the microscope. By such means, it has been found that, of the fibres of the posterior or *sensory* roots, some ascend through the white posterior columns; others cross through the gray matter of the posterior, and even of the anterior, horn, then spread upwards, downwards, and horizontally, and enter the posterior, lateral, and anterior columns of the same side, many of them reaching the anterior roots of the same, or of adjacent, nerves; another set decussate in the transverse commissure of the cord, cross over to the opposite side, and end, either in the gray matter, or in the posterior, lateral, or anterior columns, and even in the anterior roots of the opposite nerves; finally, many terminate in the gray matter, where they form loops, or become connected with the multipolar ganglionic cells. Hence, these fibres serve, some, as fibres of connection with the gray matter of both sides of the cord; some, to associate different nerves of the same, or of opposite sides; and possibly others, to connect the nerves directly with the gray nervous centres at the base of the encephalon. Besides this, there probably exist transverse, and perhaps longitudinal, commissural fibres proper to the cord itself.

Physiological experiments, especially those made by Brown-Séquard, by dividing some portions of the cord, and leaving others, show that the effects of *sensory* impressions pass through the white substance for a certain distance upwards and downwards, into the gray matter, and then cross over to the gray matter of the *opposite* side of the cord, and so ascend towards the brain. This conducting power is said to be greater in the central part of the gray matter, than in the cornua. The path of sensations appears to be chiefly in the gray matter of the central parts, and of the posterior half of the opposite side of the cord. The white posterior columns do not appear, in any way, to assist in conveying the effects of sensory impressions upwards. The experiments from which these conclusions are drawn, consist, first, in dividing or destroying the posterior white column with the point of its cornu of gray matter, in which case sensation is retained in the parts below the injury; and, secondly, in preserving the posterior column and gray cornu, and dividing or crushing all the rest, when sensation is lost. To show the divergence of the paths of sensation, upwards and downwards, the ascending and descending posterior roots of the nerves are traced far into the gray matter, which is then cut, first above, and then below the nerves: it is found that sensation is not completely destroyed, till the gray matter is cut in both directions. So, also, when the posterior columns are divided transversely, both surfaces continue to conduct sensory impressions, showing the descent of these impressions in the lower part of the cut cord, before they cross over to the opposite side. In proof of the decussation of the path of sensations, it is found that, on dividing the right half of the cord, in the neck or back, sensibility ceases on the opposite side of the body only, whilst motion is destroyed only on the same side. An additional remarkable result takes place viz., that, on the same side as the cut, especially when this is in the posterior portion of the cord, the sensibility is, after a few hours, much exalted, and remains so for many days, or, to a slight degree, for months. This effect, it is conjectured, is due to a dilatation of the minute vessels of the parts on that side, through the suspension of the action of certain sympathetic vasi-motor nerves, which are connected with the injured part of the cord. This increase of sensibility, or *hyperæsthesia*, is accompanied by fulness of the vessels, and by an elevation of the temperature of the part. It may be due to simple inflammation, propagated from the wounds inflicted on the cord, and on the soft parts and bones, in exposing the cord itself. It has been seen after section of the anterior or motor columns alone. It has also been stated, by able experimenters, that in dividing the cord on one side, there is a certain diminution of sensation on both sides, but a greater one on the opposite side; any remaining appearance of sensation, in the latter case, being dependent on painful reflex movements.

It is believed by Brown-Séquard, that different kinds of sensory impressions have different channels, none of which are substitutes for the others—touch, pain, the sense of temperature, and the muscular sense, each having its own channel. Schiff also states, that the higher form of common sensibility, which is named tactile sensibility, as distinguished from a mere sense of pain, travels up along a different path to that of ordinary sensation. According to him, tactile sensibility is lost on the cut side, so that its path is in the white columns of the same side, and does not decussate or pass over to the other side; whereas the path of common sensation is through the gray matter, in which the impressions are diffused in various directions. He further adds, that it is the common sensibility only, and not the other forms of sensation, which is exalted on the same side, and diminished on the opposite side; and that this effect is only temporary. Some singular results follow a median section down the spinal cord. According to Brown-Séquard, if the cord be cut along the middle line in the lumbar region, sensation is lost, on both sides, in all the parts below the cut; but if the section be higher up, sensation is lost only in the parts supplied by nerves from the corresponding piece of the cord, and not in the parts lower down. These results appear to show that the decussation of the paths of sensation, in reference to all the parts below, takes place in the lumbar enlargement of the cord, and that therefore both sides are paralyzed as to sensation; whereas, higher up, the decussation of the paths of sensory impressions from the parts below, has already taken place, and so those are not cut in the median section, which destroys only the decussation of the nerve roots or sensory paths of the adjacent nerves. Other observers conclude that this decussation of the paths of sensation is not quite complete, but that some sensory fibres may pass up in the gray matter, or in the posterior white columns of their own side; for they have found that, after median longitudinal division of the cord, some sensory impressions still pass up on their own side. (Schiff.) It may be that the arrangement of the fibres of the cord differs in the different species of animals, which have been the subjects of experiment. It will immediately be seen, that a median section down the spinal cord, does not paralyze the muscles, or affect the voluntary movements. It has been found, that so perfect, or generally diffused, is the conducting power of the gray matter of the cord for sensory impressions, that the smallest portion left, either in a transverse or longitudinal direction, is sufficient to conduct, though in a limited degree, sensory impressions across to the opposite side, or in an upward direction. This facility of conduction caused Schiff to compare the gray matter to a mass of fluid, in which vibrations are transmitted equally in all directions. From the fact, that the gray matter of the cord is itself insensible, though a conductor of sensory impressions, he named it the *æsthesodic substance*, because it is the path of sensory impressions (αἴσθησις, aisthesis, *sensation*, and ὁδός, odos, a *path*), and yet not sensitive itself.

The path of the *voluntary motorial* stimulus has next to be considered. The anterior or motor roots of the spinal nerves proceed from fibres, which, as already mentioned, may be followed through the anterior cornu of the gray matter of the cord; some pass upwards and downwards into the anterior and lateral columns; others come into relation, in the gray matter, with the fibres of the posterior roots of the same side; whilst another set cross over to the opposite side of the cord, decussating there with fibres coming in the other direction, and ending in the anterior and lateral columns of that side, or even in the anterior roots of its nerves; many come into close connection, or are continuous, with the posterior roots of the same side; and, finally, many end in the gray matter, where they become connected with the multipolar cells. These fibres, like those of the posterior roots, resolve themselves into proper fibres of origin in the cord, fibres of association of the nerves of the same and opposite sides, and longitudinal fibres, which probably connect the nerves directly with the encephalon.

The path of the voluntary motorial stimulus appears to be downwards, through the anterior column and adjacent part of the lateral column of white substance, and perhaps through the anterior cornu and gray matter. When the posterior columns are divided transversely, no apparent loss of volitional power takes place. If, however, the anterior and lateral columns be cut across, the parts below are paralyzed, on the same side, as regards voluntary motion. If the section be made high up in the cord, division of the anterior white columns was said, by Bell, to have the same effect; but Brown-Séquard maintains, that in this region the lateral columns convey the volitional impulses, the gray matter being also slightly concerned in this act. If the cord be cut completely across, and the cut end of the lower portion, which is detached from the brain, be irritated on the section of its antero-lateral column, convulsive movements will take place in the muscles below; but if the posterior part of the section be irritated, no movements occur. And it may be added, that if the cut ends of the anterior columns of the part still in connection with the brain, be irritated, no movement takes place; whereas, if the cut ends of the posterior columns be irritated, pain is produced.

A most remarkable accident, which occurred to a gendarme in Paris, has supplied experimental proof of the paths of voluntary motion and sensation, in the human subject. He was struck in the back of the neck by a knife; his right arm was slightly, and the right half of the trunk and the right leg completely paralyzed, as regards voluntary motion; whilst sensation was quite perfect in all these parts. He died in four days. The point of the knife was found in the vertebral canal, having passed through the arch of the sixth cervical vertebra on the right side; it had exactly divided only the anterior column, the lateral column, and the adjacent part of the gray matter on the right side of the spinal cord.

It remains to notice that, as already observed, the median longitudinal section of the cord, in animals, does not destroy voluntary motion. It should also be remarked, that in certain cases of disease of the spinal cord, the posterior columns of the cord have been found disorganized, without there having been any impairment of sensation. As the term æsthesodic has been applied by Schiff, as already mentioned, to that substance of the cord, which is concerned in the conveyance of sensory impressions, so, for similar reasons, the term *kinesodic* (κίνησις, kinesis, *motion*, and ὁδός, odos, *a path*), has been employed to designate the substance concerned in the conduction of motorial impulses, a property, which, he likewise believes, it can exert in any direction.

The sum of our information on the whole subject is this: First, that the paths of *sensory* impressions reach the gray matter of the cord, the interposition of which is regarded as an essential condition of sensitive conduction; diffusing themselves in the gray matter, they pass to the opposite side, and then ascend towards the brain; so that they decussate even at the lowest part of the cord. Secondly, that the paths of *voluntary* motion descend from the brain, not through any intervening gray matter, but along the white fibres of the anterior and lateral columns, perhaps also through white fibres lying in the adjacent gray matter of the same side of the cord, and that they do not decussate in it. Numerous fibres certainly cross over from one side of the cord to the other, in the anterior columns; but these, which belong to the anterior roots of the nerves, are perhaps concerned in the reflex, and not in the voluntary movements. This difference in the paths of sensory and motor impulses along the cord, and the decussation of the former within it, explain cases of disease of the cord, in which there are observed, muscular paralysis of one limb, and anæsthesia or paralysis of sensation in the other.

Considered as an anatomical question, it does not seem possible that all the fibres, either of the sensory or motor roots of the spinal nerves, can ascend directly up to the seats of common sensation and of volitional impulse, in the brain; for the mass of the cord is not increased as it ascends, *in proportion to the number of nerves* which join it; indeed, *most* of the *fibres* of the nerves appear to end in the cord itself; and many of its own longitudinal fibres appear to be commissural, serving to connect the nerves with many segments of the cord, or its own segments with each other. Many of the nerve-fibres appear thus to be concerned in the exercise of functions dependent on the cord itself, acting as a special nervous centre. The propagation upwards of sensational impressions, is properly accomplished chiefly through the gray matter, by indirect electrotonic changes excited in it; whilst the volitional impulses descend chiefly through longitudinal fibres, indirectly excited from above. The conducting power of the gray matter, moreover, in both cases, seems now to be well established; it contains, however, many intermixed white fibres. It has been observed, that the posterior columns of the cord are highly sensitive to stimuli on their surface, but not in their interior; whilst the antero-lateral columns are not sensitive either on their surface, or in their interior (Chauveau).

The preceding experiments demonstrate the conducting properties of the spinal cord, both as concerns its gray and its white substance, and in reference both to sensory and to voluntary motor impressions; and they show, moreover, by the complete annihilation of voluntary power in the parts below a cross section through its substance, that it does not originate voluntary motorial stimuli, nor effectually feel sensorial impressions. But, in regard to motion in general, we shall find that the cord is a governing centre for a particular class of *involuntary movements*, which have repeatedly been mentioned, viz., the *reflex movements;* and, in reference to sensory impressions, we shall find that the cord, when in a state of integrity, can not only conduct such impressions to the common sensorium, but may also *transfer* them from nerve to nerve, and cause them to *radiate* from one branch of the same nerve to other branches.

The *transference* of sensation from one nerve to another, through the cord, is illustrated by the occurrence of pain in the knee-joint, in cases where the disease is actually in the hip, or by the feeling of pain in the heel, when the kidney is the seat of irritation, or by the pains felt in the limbs, in certain examples of disease of the brain. In these cases, the sensory impressions are said to be transferred from nerve to nerve, through their connecting bond of gray substance in the cord; for they have only been noticed where the nerves retain their connection with their proper gray centres. The *radiation* of sensations from one branch of a nerve to another, is illustrated in the case of neuralgic affections proceeding from a local injury to one branch of a nerve, say of the skin of the hand, and also when a nerve entangled in a cicatrix, or in the sides of a growing tumor, causes pain, not only in the part, but also along the track of other branches of the same nerve; these phenomena are observed only so long as the nerves are in connection with their gray centres. It is open to question, whether a very powerful stimulus to one nerve-fibre, may excite adjacent fibres, as, for example, in the interlacing parts of a plexus, and so produce pain referable to distant parts; we have elsewhere seen, that a stimulus applied to one nerve, may communicate itself to a neighboring nerve (p. 229). This occurs more commonly, when the nervous centre connecting the nerves, is in a particular condition of excitement. Thus, in a highly exalted state of the nervous excitability, as, for example, in the condition of inflammation, or of irritation produced by strychnine, the ordinary insulation of the nerve-fibres may, as it were, be broken through, and then stimuli applied to one set of fibres may excite adjacent ones directly, without the intermediation of the gray matter of their common nervous centre.

It remains to notice the reflection of impressions, brought by *afferent* fibres to the cord. upon *efferent* fibres proceeding from the cord, producing what are called *reflex actions* or movements, and constituting what is known as the *reflex excito-motory* power of the cord. The existence of such a controlling or regulating power in the cord, over the muscles supplied by nerves issuing from it, is shown by the fact, that a decapitated lizard or frog will remain standing on its feet, and will manifest special movements, if the skin be irritated. On further division and subdivision of the trunk and tail, each segment of the lizard, containing its portion of the spinal cord, still continues to exhibit similar movements. Again, when the spinal cord of a frog is divided, all voluntary motion, as we have already seen, ceases in the parts below. If the posterior columns of the severed portion of the cord be now irritated, convulsive movements follow in the muscles below and above, resulting from the indirect artificial stimulation of the motorial tracts and motor nerves proceeding from them, and not from a direct irritation of those tracts, the effects of which would be limited, as in the case of a pure motor nerve, to the muscles supplied from the stimulated portion of the cord. But, furthermore, movements may be excited in those muscles, by the application of a stimulus to some distant and excitable part of the skin of the animal; the stimulus employed, first excites the extremity or trunk of an afferent or so-called sensory nerve, the effect of the impression so produced passing up to the gray nervous centre, the cord, and thence being, as it is specially termed, *reflected* on to certain efferent, or so-called motor, fibres, and so reaching the muscles which are excited to contract. This is the mechanism of all reflex movements. All require for their execution, an afferent nerve, an efferent nerve, and an interposed gray nervous reflecting centre, or centre of reflection. The stimulus excites the afferent nerve, this the reflex centre, and this again the efferent nerve; hence the term *excito-motor*, or excito-motory, applied to the reflex phenomena and acts. They are also named *automatic*.

The experimental illustrations just given, in the cases of decapitated animals, or of animals the spinal cord of which has been divided, show the independence of these acts, of the cerebrum, or of any cerebral interference; they prove accordingly, that the spinal cord is, in regard to them, an independent centre of nervous action. These movements are strictly involuntary, and they may occur quite independently of sensation and consciousness; they are not irregular or convulsive movements, such as follow the pinching or irritating a motor nerve, or the motor columns of the cord; but they are definite and regulated movements, depending on the distribution of the afferent nerve, to the ends of which the stimulus is applied, and on the particular efferent fibres, upon which the effects of this stimulus are reflected.

These reflex movements are even more extensive and powerful, when the spinal cord is separated from the brain, or seat of volition, than when the cord and medulla are still connected with it. According to some, this is owing to the loss of a controlling power exercised by the brain; but according to another view, it is rather due to the fact, that when the cord is severed, the whole force of the excitation is necessarily thrown upon the ganglionic centres of the cord alone. Reflex movements are more easily excited by irritation applied to the free extremities of the afferent nerves, as to the skin of a frog, than by stimuli, even of a stronger kind, applied to the trunks of those nerves, though the pain in the last case may be as great or greater. This is another proof, that there is no necessary relation between sensation and reflex action. So in cases of diminution of sensation, and loss of voluntary motion, in the lower half of the body, the controlling power of the brain being absent, the reflex action is increased, and slight stimulation of the skin, unfelt by the person, produces more powerful reflex movements, than the stronger stimuli of pinching and pricking, which may be felt by him. The phenomena observed, after injury of the cord, further prove, even in the human subject, that the conveyance of volitional impulses, may be completely destroyed by a certain lesion, which nevertheless does not interrupt the transmission of reflex, or excito-motor, impressions on its afferent nerves; and, further, that the effects of such impressions, may be widely diffused through the cord. It frequently happens that such reflex phenomena, after injury, do not manifest themselves, or at first only feebly, but that subsequently they become stronger, when the effects of concussion, for example, have passed off, though not so far as to restore the volitional power.

Reflex movements ordinarily have a special object or design, and are therefore said to be *purposive;* a character which, as we shall frequently find, by no means implies that they are either accompanied by sensation, or directed by the will. Most frequently, they may, in general terms, be said to have a *conservative* object in the animal economy. Besides the example of reflex movements, performed through the cord, exhibited in the hinder limbs of the frog, the spinal cord of which has been divided, instances of reflex movements, performed through the cord, may be adduced in the human subject, when unconscious, as in sleep, or under the influence of chloroform, or when awake, in a state of disease, or even in health. The withdrawal of the feet, when tickled during sleep, the flinching of a patient under chloroform, from any cause of irritation applied to the surface, also the involuntary raising of the foot, from the pricking of a needle, and the sudden withdrawal of the hand, on which hot sealing-wax has fallen, are instances of involuntary reflex movement taking place under different circumstances. In the two latter cases, conscious sensation accompanies the reflex acts, which are therefore designated *sensori-motor;* in the two former cases, there is a greater or less approach towards a suspension of sensation; but it may not be wholly lost, though the memory of it is not retained. In the first instance, that of sleep, a similar difference of opinion may obtain, in the mode of interpreting the phenomena, conscious sensation being held, on the one hand, to be merely blunted, or, on the other, to be entirely suspended. But there remains another set of examples, in which there can be no doubt of the complete annihilation of sensation, and of all its attendant consequences, although active reflex movements can be produced by external or even internal stimuli. Thus, in injuries or diseases which cause compression, laceration, or softening of the spinal cord, to such an extent as completely to destroy both voluntary power over the limb, and likewise all sensation in it, violent reflex movements may be excited, in the so completely paralyzed limb, by the application of stimuli to the extremities of the afferent nerves, as by tickling, pricking, or electrifying the skin of the soles of the feet, when a movement of withdrawal will take place, over which the patient has no control, as he would ordinarily have, if the cord were sound, and of which, as well as of the sensations which the stimuli are calculated to produce, he has no perception or consciousness whatever, provided his eyes be closed. An instance is recorded by John Hunter, of a man whose spinal cord was ruptured. Being asked, when his feet were irritated, whether he could feel the irritation which excited them to move, he replied, "No, but you see my *legs* do." Such cases demonstrate perfectly, not only the involuntary character of the reflex movements in question, but also prove that they may take place without conscious sensation. The apparatus concerned in their production, is exactly similiar to that of the movements excited by irritation of the skin, in the hind limbs of the frog, the spinal cord of which has been divided; that is to say, it consists essentially of *afferent* or *incident* nerves, of a *reflex gray centre*, and of *efferent* or *motor* nerves. In certain experiments on the frog, the purposive character of these movements, even where there can be no suspicion of volition or consciousness, which must be one and indivisible, is well illustrated. Acetic acid, which powerfully stimulates these animals, when applied to the inner side of the knee joint, or to the side of the abdomen of a *decapitated* frog, excites the animal to rub that portion of the skin with the same foot; and, if now that foot be cut off, similar attempts are then, more or less effectually, made with the opposite foot.

Lastly, the necessity for the interposition of a reflex gray centre, between the afferent and efferent nerves, is shown likewise by experiments in animals, and by observation in cases of injury and disease in man. For if the severed portion of the spinal cord in the frog be destroyed, as by passing a wire down the spinal canal, stimulation of the nerves of the skin will no longer produce reflex movements, although the contractility of the muscles, and the excitability of their efferent nerves, still remain active, as may be shown by pinching one of those nerves, when the muscles, to which it is distributed, will immediately contract. So, too, in cases of disease of the spinal cord, when the distal part, below the seat of any disintegrating injury or disease, becomes itself softened, and so loses its vital properties, reflex movements can no longer be excited in the lower limbs, by stimulating the skin. An afferent nerve cannot therefore convey, or transmit, the effects of a stimulus upon it, to an efferent nerve directly, but can only reflect those effects indirectly, through interposed gray matter. From this, it has been inferred that the nerve cells of the gray matter, are, in some way, specially concerned in this office of reflection, but it is not yet known how they act. The most prevalent opinion is, that a particular afferent fibre ends, as described in p. 53, in one of the processes of a nerve cell, and that the efferent fibre arises from another process of the same cell. Where the cells have more than one process, more than one afferent or efferent fibre may, it is thought, be so connected with it. Or a succession of nerve cells may be interposed between the incident and the motor fibres, and so may extend or spread the effect of the stimulus. Again, it is held by some, that perhaps the reflex office of the gray matter, is effected by the mere proximity of the nerve-fibres passing through it, between or amongst the nerve cells, without there being any direct connection between them.

A further question arises as to whether there are special afferent fibres concerned in conveying a reflex stimulus, different from those afferent fibres destined to convey the sensory impressions. It is certain that, if this be so, no anatomical difference between the several afferent fibres in the posterior root of a spinal nerve can be detected.

It appears probable, however, that their difference in function, that is, whether they convey the effects of sensory impressions to the gray matter of the cord, thence to be conducted to the brain, or whether they convey the effects of stimuli to the gray matter of the cord, thence to be reflected on to the efferent reflex nerves, depends upon the nature of their connections with the cells of the gray matter. Neither can any structural difference be found amongst the efferent fibres of the anterior roots; and it is presumable, therefore, that the particular efferent fibres, concerned in voluntary movements, and in reflex involuntary movements, owe their special mode of action to the fact, that the former descend continuously from the *cerebrum* (that is, from the corpora striata), whilst the latter probably originate in connection with the nerve cells of the gray matter of the cord. It appears, moreover, both from experiment and from observation in cases of disease, that the posterior white columns of the cord, and the contiguous gray matter, the nerve cells of which are peculiar, may have some special relation to the reflex function. The various instances in which the spinal cord acts as a reflex nervous centre, and some further points concerning these reflex movements, will be hereafter considered.

It remains to be noticed, that the spinal cord exercises, probably by a continuous reflex action, a permanent influence on the muscles, upon which the so-called *tonicity*, or *tonic state*, of those organs, depends; for when, in an animal, the cord is destroyed, or carefully removed from the spinal canal, all the muscles become atonic or flabby, and the habitually contracted condition of the sphincters is lost. The rigor mortis, nevertheless, takes place as usual. This tonicity, or tension, is supposed to depend on a slight but constant exercise of a stimulus, originating in the cord, upon the entire muscular system. It does not depend on the brain, for decapitated animals will retain their position; but the limbs immediately become flaccid and fall asunder, when the cord also is destroyed. It is from loss of this tonicity in the paralyzed muscles of the face, that, independently of the will, the features are drawn over to the opposite side by the still healthy muscles. That this effect does not depend on loss of the contractility in the paralyzed muscle, is shown by the fact that the muscle will still contract, on the application of a direct stimulus.

Irritation of the cord of a recently decapitated animal increases considerably the force of the heart's beats; it also accelerates the contractions of the intestines, ureter, and bladder, and even of the small arteries. These phenomena indicate a partial dependence of those organs on the spinal cord, through the intervention of the sympathetic nerves, which constitute the only channel of communication between them and the cord.

Partial extirpation of the cord from animals is borne for a very long time, and, in birds especially, is followed by loss of sensibility and mobility in the corresponding parts of the body. Complete removal of the cord, in mammalia, causes death, only after one or two days, provided hemorrhage be guarded against. Partial destruction of the cord by a wire is much more speedily fatal, death occurring in a few hours, and more quickly, the nearer the injury to the cervical region;

total destruction of the cord, by the same means, is almost instantaneously fatal.

Functions of the Medulla Oblongata.

In a physiological, as well as in an anatomical point of view, the medulla oblongata is to be regarded as a continuation upwards of the spinal cord; but owing to the importance of the organs, the nerves of which proceed from it, its functions are of greater consequence than those of the cord. It is further remarkable as being the seat of the *decussation*, or crossing from one side to the other, of the paths of the voluntary motorial stimulus from the cerebrum above, to the spinal cord below; this decussation of the motor tracts occurs almost entirely at the lower part of the medulla oblongata. (Brown-Séquard.)

The medulla oblongata acts, like the cord, as a *conductor* of the effects of *sensory* impressions upwards, from the cord to the cerebrum; the paths of such sensory impressions, are probably, on grounds of analogy, through the gray matter, and the continuations upwards of the ascending fibres of the posterior pyramids, and not through the restiform bodies, which pass up to the cerebellum. These paths do not again decussate in the medulla, having already crossed over in the gray matter of the cord. The medulla oblongata may, also, *transfer* the effects of sensory impressions, from one nerve to another; as when any irritation in the stomach, acting on the vagi nerves, produces sympathetic headache, or pains in other parts of the body. Moreover, radiations of sensation may take place through the medulla oblongata, as when the pain from a single decayed tooth is transferred to other branches of the fifth nerve, and causes pain in the corresponding tooth in the other jaw, or in various parts of the same side of the face and head.

The medulla oblongata likewise acts as the *conductor* of the effects of the *voluntary motorial* stimulus passing down from the brain, onwards to the spinal cord and spinal nerves. The paths through which this conduction takes place, are the fibres of the anterior pyramids, division of one of which produces in an animal paralysis of one side of the body (Magendie); whilst irritation of these is not followed by indications of pain, as is the case when the restiform bodies are simply touched. The fibres of the anterior pyramids decussate in so remarkable and complete a manner, that the motorial stimulus, proceeding down the peduncle of one cerebral hemisphere, crosses completely over in the medulla, to the opposite side of the cord, at the so-called decussation of the anterior pyramids. Thus, in artificial division of one-half of the spinal cord of an animal, paralysis of motion occurs, as already mentioned, on the same side of the body; whilst if the section be made opposite the decussation of the anterior pyramids, in the medulla oblongata, paralysis of the muscles follows on both sides; but if the section be still higher, in the very highest part of the medulla oblongata, the paralysis happens only on the opposite side of the body. These results are confirmed by other experiments, and by observations, in disease, in man; and these are of high importance, for sections of the medulla oblongata itself, especially of its posterior parts, are often so immediately fatal, owing to its being the centre for the regulation of the respiratory movements, that time is not allowed for the development of the effects, as regards the voluntary movements. Thus, when one hemisphere of the brain is removed in an animal, there is a diminution of power on the opposite side; and when the peduncle of one hemisphere is removed, there is a total loss of voluntary power on the opposite side of the body; so, again, effusion of blood into, or softening of, the substance of one peduncle, or of the parts above it, in man, is followed by paralysis of motion, with or without paralysis of sensation on the opposite side; whereas paralysis of those muscles, the nerves of which proceed directly from the pons or peduncles of the cerebrum, that is, from above the place of decussation of the motor columns in the medulla oblongata, is on the same side as the injury or disease; for example, cases of extravasation of blood into the left corpus striatum, or left hemisphere of the brain, exhibit, during life, paralysis of the right limbs, but usually of the muscles of the left side of the face; there may sometimes be paralysis of the opposite side of the face also, the reason of which is not known. Decussation of the paths of the voluntary motorial stimulus in the medulla oblongata is thus abundantly proved.

Many *reflex* functions are performed by the medulla oblongata, in common with the spinal cord. The afferent nerves connected with it, supply all the important surfaces and organs at the upper part of the body; viz., the skin of the face, the mucous membranes lining all its cavities, the parts of the organs of the senses endowed with common sensibility, and the lining membrane of the pharynx, larynx, windpipe, and bronchial tubes; lastly, they give branches to the heart and lungs, as well as to the œsophagus and even the stomach. These fibres, accordingly, bring the effects of excitant stimuli, from all those surfaces and parts, to the great and important reflex centre, formed by the gray matter of the medulla oblongata, from which the effects are reflected, along certain special efferent motor fibres, on to various muscles, which, then contracting, cause reflex movements of a most extensive, definite, and important kind.

Some of these movements assist in the performance of the functions of special sense, as *e. g.*, the movements of the pupil. Others are conservative or protective, in regard to the sensory organs: for example, the closure of the eyelids is a reflex act; it can even be excited in animals in which the functions of the brain have been entirely suspended or destroyed, by irritating the margins of the lids by a feather. Other reflex movements protect the respiratory apparatus; and some are absolutely essential to life, as is the case with the movements of deglutition, and especially with those of respiration; for such movements as the acts of sneezing and coughing, part of the act of swallowing, and all the respiratory movements, are of an involuntary reflex nature. They are all performed under the influence of the medulla oblongata, the injury or destruction of which, impairs or arrests them.

In reference to the respiratory functions and movements, this influence has been specially demonstrated by experiments on animals, which have yielded both negative and positive results. Thus, even in warm-blooded animals, all the parts of the brain have been gradually cut away from above, down to the medulla oblongata, and the spinal cord has then also been detached below it, and yet respiration has continued for a short time (Longet); and in the frog, both the brain and spinal cord have been removed, and respiration has been long sustained, provided that the medulla oblongata remained uninjured. Again, the medulla oblongata itself has been alone destroyed, when respiration was instantly arrested, the animal dying asphyxiated. It is sufficient for a very small portion of the back part of the medulla, in the floor of the fourth ventricle, to be destroyed, in order to produce this effect, and indeed the destruction of a very minute point, hence named the *vital knot* (*nœud vital*), has been deemed sufficient for this purpose. But there seems reason to think, that the part concerned as a centre in governing respiration, is of greater extent; it is believed to correspond with the portion from which the deep roots of the pneumogastric nerves take their origin, which occupies the back part of the medulla; for the restiform bodies and the pyramids may be removed without interfering with the respiratory acts. A transverse section through the gray matter of the medulla oblongata, at the point of the calamus, suddenly stops the respiratory movements; but after a longitudinal median section of the medulla, these continue. Hence both sides of the body possess their proper respiratory nervous centre. Irritation of the medulla oblongata diminishes the number of the respirations; a result also produced by general pressure on the brain, the effects of which are transmitted to the medulla. The paths of conduction of the motor impulses concerned in respiration, named, by Sir C. Bell, the *respiratory tracts*, are located in the white fibres of the lateral columns of the cord. (Bell, Schiff.) The office of the medulla oblongata, as the controlling centre of respiration, affords an explanation of its importance in regard to the vital activity generally. Through it, the heart is indirectly, and also directly, affected, for the vagi nerves, which regulate the heart's movements, arise from this part. Galvanic irritation of the medulla, like that of the vagi nerves, causes temporary arrest of the heart's actions; its destruction diminishes the frequency and strength of those movements.

There is reason to conclude, from analogy, that the reflex movements of deglutition must likewise have their special governing centre, which is supposed to be placed at the back of the medulla, near the vital knot.

As a reflex centre of a more general kind, the medulla oblongata is further regarded as the seat of excitation of symmetrical epileptic seizures, such as occur after ligature of the great vessels of the neck.

The medulla oblongata is probably also a centre for certain parts of the sympathetic system; and a cross section through the restiform bodies, like division of the posterior columns of the cord, is followed, probably from similar reasons, by an exalted sensibility of the trunk and limbs.

Like the reflex acts of the spinal cord, those which take place through the intervention of the medulla oblongata are likewise independent of the will, and are not necessarily associated with consciousness, for an animal will suck an object placed between its lips, or swallow a mass of food placed on the back of the tongue, or close the eyelids, if these be irritated, even though the functions of the brain be suspended or destroyed. Persons in a profound state of comatose unconsciousness and insensibility, from the effects of concussion of the brain, or of chloroform or opium, will perform the same acts, and so too will acephalous monsters. It has also been shown that the contractile movements of the pupil, produced by the action of light, and intended for protective purposes for the retina, and which are ordinarily accompanied by the special sensation of light, will occur in cases of amaurosis, a disease characterized by alteration and consequent insensibility of the retina, and in which there is absolute blindness. A strong light also sometimes causes sneezing, by a reflex action through the optic nerve, the cerebro-spinal centres, and the nerves which govern the respiratory movements; this movement is automatic and *sensori-motor*, for it is accompanied by pain.

Furthermore, the medulla oblongata is, in some way, concerned in the special senses of *hearing* and *taste*, containing, as it does, the deep origins of the portio mollis of the seventh pair or auditory nerve, of the glosso-pharyngeal nerve, and of the gustatory fibres of the fifth pair. Its gray matter either constitutes the special centres of the auditory and gustatory senses, the effects upon which are afterwards transmitted to the common sensorium in the cerebrum; or it serves as an essential, but non-sensitive conducting path of the effects of sonorous vibrations or of gustatory impressions, in their way upwards to the cerebrum.

It has been supposed that the gray matter of the *olivary bodies*, with which the roots of the hypoglossal nerves are said to be connected, has some special office in the government of the tongue and adjoining parts, in the motions necessary to speech (Schroeder Van der Kölk); but this view has not yet received the general sanction of physiologists.

The formation of sugar in the liver is increased, by puncture, even on one side, of the back of the medulla oblongata (Bernard), to such a degree, that the urine becomes saccharine. Whether this is indirectly owing to an interference with the respiration, or to some action on the secreting power of the liver itself, is not known.

Functions of the Pons Varolii, Cerebral Peduncles, and the gray masses at the base of the Cerebrum, viz., the Corpora Striata, Optic Thalami, Corpora Quadrigemina, Corpora Geniculata, Pineal, and Pituitary Bodies.

In the first place, setting aside the transverse fibres of the pons, which form the middle peduncles of the cerebellum, and also leaving out of consideration the superior and inferior peduncles of that organ, the latter being the continuation upwards of the restiform bodies, we may regard the longitudinal fibres and the gray matter of the *pons* and cerebral peduncles, as physiological extensions upwards, upon an amplified scale, of the white and gray elements of the spinal cord and medulla oblongata. They accordingly receive, conduct, or transmit the effects of *sensory* impressions, upwards to the cerebrum; and, in particular cases, probably also transfer and radiate such impressions. They also conduct the *voluntary motorial* stimulus, downwards from the cerebrum to the medulla and cord. The paths of sensation are probably through the gray matter and white fibres of the central and posterior portions of the pons and of the cerebral peduncles; whilst the paths of motion are down through the white fibres forming their anterior or under portions. Furthermore, the gray matter of these parts forms reflex centres for the performance of most extensive and powerful reflex acts, being, in this sense, quite as energetic as the medulla oblongata and cord. Some of these reflex movements are of a local kind, such as those which regulate certain of the movements of the pupil; others are of so general and purposive a character, as to have led to the supposition that here, at length, we arrive at a portion of the nervous centres, in which not only *conscious sensation* may be realized, as supposed by Longet, but in which some feeble *mental directive power* may be exercised. But this is not proved.

In animals in which, the cerebrum and cerebellum being taken away, the pons and medulla oblongata are left uninjured, and connected with each other, cries and attempts to remove the objects of irritation, have been found to follow pinching the tail, and the application of ammonia to the nose; if left quiet, the animal remains motionless, but if put into an uncomfortable position it immediately resumes a more easy one. All such movements, however, cease when the pons is removed from the medulla. (Flourens, Longet.) The movements appear to be as perfect as the natural sensori-motor reflex movements, and resemble the instinctive movements of animals, but they are not really voluntary.

Experiments on the pons and cerebral peduncles are followed by remarkable results. Thus, irritation of the deep parts of the *pons* causes convulsions in various regions of the body, and, if the brain be left, obvious signs of sensibility. A section of the transverse fibres of the pons leading to the cerebellum on one side causes most curious rotatory movements on the part of the animal, which turns *towards* the injured side, contrary to what happens in certain other examples of rotation to be presently mentioned, produced by sections of other parts of the nervous centres. Section of the corresponding fibres on the opposite side arrests this rotatory movement. Division of these fibres on one side also produces a downward movement of the eyeballs on the injured side, and convulsive rolling movements in the eye of the opposite side. Lastly, a hyperæsthesia similar to that which follows sections of the spinal cord, especially of its posterior portion, occurs after sections of the back or front of the pons; but this is noticed on the opposite side of the body, and not on the same side, as is the case when the cord is injured.

The *cerebral peduncles* are, like other portions of the longitudinal parts of the nervous centres, conductors of sensorial, voluntary, and reflex impressions, upwards and downwards, along special sets of fibres, set apart for each function. Thus, the sensorial paths are connected with the optic thalami, and the motor tracts with the corpora striata and corpora quadrigemina. Division of both peduncles is followed by complete loss of sensibility and voluntary movements in the body. When one peduncle is partially divided, remarkable rotatory movements ensue, *from* the injured *to* the sound side, which have been attributed to a loss of the controlling power of the cerebrum over the half of the body opposite to the injury; the circles of movement are larger, the nearer the section is made to the cerebrum. Complete division of one peduncle causes the animal to fall on the opposite side, because it paralyzes that side, though the reflex functions remain intact.

Irritation of the peduncles, after the brain has been removed, causes contractions in the muscles generally, and also in the stomach, intestines, and bladder; these effects show conductive power, partly through the pons, medulla, spinal cord, and spinal nerves, and partly through the sympathetic, which is connected not only with the medulla and cord, but also with parts of the brain higher up.

As to the gray masses, sometimes named the cerebral ganglia, found at the base of the brain, the gray matter of the *corpora quadrigemina* appears to be associated with the function of sight; for removal of these parts causes blindness, which likewise usually follows their destruction by disease. Atrophy or wasting of these bodies, may result from atrophy of the eyes. The destruction of one causes loss of sight in the *opposite* eye, and temporary debility of the opposite side of the whole body. The corpora quadrigemina are also highly irritable, and exercise reflex functions of an extremely active and important kind. Thus, irritation of both, or even of one, of these gray centres, produces contraction of both pupils, and, during life, such movements are doubtless caused by impressions conveyed from the retinæ, through the afferent fibres of the optic nerves and tracts; and the experiment last mentioned, on one of these bodies, is regarded as a proof of the transmission of impressions from both retinæ, backwards through the optic commissure, along both optic tracts. Partial removal of the corpora quadrigemina produces partial blindness of a temporary kind, debility of the muscles on the opposite side of the body, and sometimes giddiness, or slight rotatory movements; possibly from the interference with the sense of sight. Their complete removal is followed by total blindness, and by dilatation and immobility of the pupil. The general consciousness is not interfered with. Besides the slight rotatory movements just mentioned, general convulsions sometimes follow experiments on these parts; but these are both supposed to be owing to unavoidable injury, or irritation, of deeper-seated parts. That the corpora quadrigemina are connected with the exercise of the function of sight, is therefore undoubted, and it is probable that they are either the actual centres of visual sense, or the essential paths for the reception and conduction of visual impressions to a common sensorium. It is, perhaps, through this office, that the effects of injuries of these centres, on the general muscular movements, may be explained, for vertigo may be produced by blinding one eye, or by causing the humors of one eyeball to escape.

The office of the *corpora geniculata* is unknown; from their anatomical connections, they might be supposed to be associated with the exercise of the function of sight, but they may be merely sympathetic ganglia.

The large *optic thalami* are supposed also to be concerned, in some way, in the sense of vision, but not to the degree indicated by their name; for when they are completely destroyed or removed, the sense of sight and the action of the pupil still remain. Irritation of the optic thalami of one or both sides, is not followed by contraction of the iris; such irritation causes either no signs, or very slight indications, of pain, and no convulsions. Section of one, is followed by rotatory movements, usually *towards* the opposite side, but, it is said, in the frog, towards the injured side; such movements differ from similar movements induced by injuries of other parts of the brain, in the fact that the animal continues *standing*. After removal of the cerebral hemispheres, including the corpora striata, the ability to stand and walk remains; but if one optic thalamus be cut away, the animal either exhibits rotatory movements, or is paralyzed on the opposite side and falls. (Longet.) It is stated by Schiff, that when the anterior three-fourths of the thalamus are destroyed, the rotation is towards the injured side; whereas, when the posterior fourth is destroyed, it is towards the sound side. By some authorities, the optic thalami, though themselves insensible to direct irritation, are believed to be the great foci of all the sensory nerves, and their gray matter possibly the *common sensorium*, or the nervous centre concerned in common sensation.

The functions of the *corpora striata* are also uncertain. Their removal in rabbits, is said to leave sensation and voluntary motion equally unimpaired; for, though at first passive, after a time, on being irritated, the animal manifests progressive movements of leaping, until it meets with an obstacle, when it again becomes quiet. (Schiff.) Mechanical irritation of these bodies is said to produce neither pain nor movement. Extravasation of blood into one corpus striatum, causes paralysis of the muscles of the body on the *opposite* side, owing to the decussation of the pyramids, and of the facial muscles usually on the *same* side, though sometimes on the opposite side also; why, is not known. If convulsions occur, they are also usually on the *same* side as the paralysis; in this case, the corpora quadrigemina are also commonly injured. If paralysis happens on one side, and convulsions on the other, there is usually lesion either of the corpus striatum, base of the brain, or cerebral peduncles, and also of the medulla oblongata on the same side, viz., on the side on which the convulsions occur.

As the course of the posterior or afferent fibres of the peduncles, is chiefly through the optic thalami, and the course of the anterior or under set of efferent fibres, is chiefly through the corpora striata, it has commonly been concluded that the *corpora striata* are chiefly concerned in the function of *motion*, and the *optic thalami* in the function of *sensation;* but these views are more or less hypothetical. It has also been suggested that both the corpora striata and the thalami are sensory ganglia, and have the same relation to the nerves of touch, or common sensation, as the olfactory, optic, auditory, and gustatory ganglia have to their respective nerves. Disease of the optic thalamus, is followed by hemiplegia, *i. e.*, paralysis of both sensation and voluntary motion of one-half of the body, on the opposite side: disease of the corpus striatum has, however, the same effect. It has also been suggested that the optic thalami may be the organic seats of the *emotional* part of our mental nature, in which case, they must act as sensorial centres, recognizing the changes which occur in the production of ideas, within the cerebral hemispheres. A still further extension of this view, regards the thalami as the seats of *consciousness of the mental state*, ideational, emotional, rational, and volitional; in this case, just as the sensory nerves and sensory tracts bring impressions from without, to the common sensorium in the optic thalami, and produce sensational consciousness, so it is supposed that the convergent or descending fibres, which pass from the cerebral hemispheres to the thalami, and which Reil named, as we shall see, the *nerves of the internal senses*, may be the paths by which the various actions of the brain itself, may be recognized by the same sensorium, and so cause all the varieties of mental consciousness. (Carpenter.) This ingenious view is, at least, highly suggestive.

From the present state of our knowledge, we may suppose, first, that the gray matter of these large ganglionic masses, the optic thalami, together with the gray matter diffused through the peduncles, pons, medulla oblongata, and spinal cord, constitute the true immediate centres for the reception of all kinds of sensory impressions, with the exception of those of smell, viz., those of common sensation, the sense of temperature, the tactile sense, perhaps the muscular sense, and the sensations of sight, hearing, and taste. Secondly, it would appear that in other parts of the gray matter, this portion of the great cerebro-spinal axis, from the corpora quadrigemina, corpora striata, and thalami, downwards through the peduncles, pons, medulla oblongata, and spinal cord, we have a *great centre of motorial excitability* (Sharpey), through the agency of which, all the involuntary reflex movements, whether *sensori-motor* or *excito-motor*, are performed.

Whether the large mass of gray matter, above supposed to be engaged in sensation, is itself the *true sensorium*, or actual seat of the *conscious sensation* of bodily conditions, as is commonly believed, or of both bodily and mental states, as suggested by Reil and Carpenter, or whether the impressions produced in it, according to the sense which excites them, must react, in some way, along the radiating fibres which expand from their upper end into the cerebral hemispheres, in order that conscious sensation should be realized, is unknown. It would seem certain, however, that perception or the association of sensations with their causes, ideation or the formation of ideas, memory, and the processes of comparison, combination, and determination of differences, which are implied in reasoning, and, lastly, the resulting volition or will, involve the material operation of the cerebral hemispheres.

Furthermore, whether, in the exercise of this will, in producing voluntary movements, the conducting fibres are prolonged directly downwards from the cerebral hemispheres through the cerebral peduncles, pons, medulla oblongata, and cord, to the motor nerves, or whether the hemispheral fibres themselves end in this great motorial centre, and thus act, not continuously or directly on the motor nerves, but through this automatic centre, so as to impose upon it definite impressions dictated by the will, is not yet fully decided. But the latter view appears supported by anatomical facts and general considerations; and, if this be true, then, even in volitional acts, the actual motor impulse, which immediately excites the muscles, proceeds from the motorial centre, as in the case of any other form of movement excited by an idea or an emotion, by a sensori-motor or instinctive impulse, or by an excito-motor irritation.

The office of the corpora striata, in the exercise of voluntary movements, may therefore be immediate or *direct*, as regards the stimulation of the muscles; but the optic thalami may also concur, in an indirect manner, in those movements, by virtue of their function as sensorial centres. It is known that all muscular movements are accompanied by an internal sense of effort to meet resistance, or by a sense of the condition of the muscles concerned; and this sensation or *muscular sense*, is more or less necessary for the proper guidance of the movements. Moreover, other sensations, especially that of sight, are commonly associated with certain movements of the body, and are sometimes their only means of guidance. In complete loss of *sensibility* in the legs, even though the power of motion remains, the act of walking is impossible, because the guiding muscular sensations are absent; but sometimes the sight may act as a substitute, enabling feeble locomotive efforts to be performed, so long as the person can see his limbs. Even when the sensibility of the skin remains, though the muscles are partly paralyzed, the same difficulty still occurs in using the limbs, unless they are watched by the eyes. A curious case is on record of a nurse, who had lost the muscular sense in one of the upper limbs, and who could only carry a child by constantly watching that limb; as soon as she turned her eyes from it, the limb would fall helpless to her side. (Duchesne.)

Functions of the Cerebellum.

The cerebellum is not concerned in the exercise of the psychical functions. Neither does it appear, in any way, to be a seat of the function of common or special sensation. Some, however, refer the so-called muscular sense to certain parts of this organ. When pricked or injured, it does not appear to be sensitive, for no sign of pain results from such irritation. Moreover, when it is completely removed, there is no loss either of common or special sensation in the animal. This organ does not appear to be directly concerned in the mental process of volition, since the will still attempts to exercise itself in an animal deprived of its cerebellum; for if the animal be then threatened, it will attempt to avoid the blow, or if it be wounded, it will seize the instrument or hand, to try and prevent itself being injured. Lastly, after the removal of the cerebellum, all the instinctive and simple reflex movements, such as those of swallowing, respiration, and others, continue unimpaired.

Although the will seems unaffected by injury or removal of the cerebellum, the power of executing its various mandates, especially as exhibited in the complicated muscular acts necessary for locomotion, is evidently interfered with. If thrown down, an animal from which this organ has been removed, is unable to rise, though it seems to desire to make the effort; its movements become hurried and irregular, so that there is a want of harmony in its locomotive acts; its equilibrium is no longer maintained, and it appears as if intoxicated. If a section be made through the middle line of the cerebellum, the power of maintaining the equilibrium is instantly lost, and the animal cannot even stand, but may now turn to one side and then to another.

When the cerebellum of a bird is gradually cut away, the animal becomes restless, and its movements irregular; and when the whole organ is thus removed, it can no longer walk, leap, or fly, and loses its balance, being unable to perform any acts requiring combination of muscular movements; yet the reflex movements and sensibility, both appear to remain, as it exhibits no signs of stupor, and endeavors to avoid blows. Laid upon its back, it cannot regain its former attitude, but flutters its wings. When placed on its legs, it staggers and falls, as if intoxicated, endeavoring, however, to retain the standing posture. (Flourens.) In other cases, after gradual removal of the cerebellum, a quadruped animal has been noticed to plant all four of its feet firmly on the ground, and then, on further and further portions of the cerebellum being cut away, it moved slowly or quickly backwards. Various other phenomena have been noticed in pigeons mutilated by removal of the greater portion or the whole of the cerebellum; extension of the legs, with indisposition to flex them, though this could be accomplished by an effort, twisting of the head on the neck, trembling movements of the whole body, vomiting, purgation, and general emaciation, falling of the feathers, and depression of the natural temperature; sensation and will were not destroyed. (Wagner.) According to others, the voluntary movements became, after a few days, almost natural, even though two-thirds of the organ had been removed in pigeons. (Hartwig, Dalton.) On cutting away portions of one hemisphere of the cerebellum, the most remarkable disturbances in the movements of the animal take place; for it revolves as if it were on a spit, turning sometimes to one side, and sometimes to the other. If one hemisphere of the cerebellum be entirely removed, by a section through its peduncles, the animal also revolves in a circle; this may take place sixty times in a minute, and continue for several days. If the other hemisphere be now cut away, the animal no longer performs these curious movements. According to Magendie and Müller, the rotation is towards the injured side, but according to Longet and Lafargue towards the sound side. These differences have been referred to the position and direction of the incisions, but the explanation is not quite satisfactory. The cause of the motion is supposed to be due to the one-sided action of the muscles of the body, being no longer counterbalanced by those of the other side; but another explanation is, that it is caused, not by unbalanced voluntary movements, but by abnormal tonic contractions, excited by the injury, the spine, especially its anterior portion, being twisted, and the animal evidently trying to check the movements. Section of the inferior peduncle of the cerebellum, which connects it with the medulla, causes the animal to bend round to the injured side, from loss of power in the opposite side. Division of the superior peduncles, which pass up to the corpora quadrigemina, whether unilateral or bilateral, has no distinct effect on the movements.

In a few instances which have been met with in the human subject, of congestion or more serious disease of the cerebellum, such as extravasation of blood into one of its peduncles, or pressure from bony or other tumors, backward movements, and continued rotations, have been observed during the life of the patient. It has furthermore been noted that, in an alleged case of absence of the cerebellum, the gait was uncertain, and the intellectual powers weak, although the perceptions and sensations were perfect. (Combette.)

From all these results, it has been inferred that the cerebellum is, in some way, essential to the due regulation or co-ordination of combined or complicated muscular acts, either, according to one view, by a direct governing or co-ordinating power, or, according to another view, because it is itself the seat of the muscular sense, which then conveys impressions to the cerebrum, giving notice, as it were, of the condition of each particular muscle in action, and so furnishing information for the guidance of the cerebral volitional faculty. But as many disturbances of the locomotive function, and especially the peculiar rotatory movements, ensue upon injuries inflicted on other parts of the encephalon; and as these, when produced by sections of the cerebellum, may be counteracted by sections of other parts, it is doubtful how far this latter organ can be regarded as the real governing centre in such co-ordination of the movements. Thus, according to some experiments, when one corpus striatum is cut, the animal runs forwards; and when the optic thalamus is wounded, it turns round and round. (Magendie.) According to other experiments, sections in the fore-part of the brain, cause the animal to turn in a large circle; sections further back, produce rotations in smaller circles, and when one peduncle of the cerebellum is cut, the animal revolves on its own axis. (Schiff.) Even sections of any of the three semicircular canals of the internal ear, in pigeons and rabbits, are also followed by similar rotations (Brown Séquard), and still more remarkable and definite movements have been noticed after such experiments, the animals, according to the particular canal divided, throwing summersaults in definite directions, whenever they attempted to move. (Flourens.) These movements may depend on some disturbance of the function of hearing, but this is not established.

The doctrine, that the cerebellum is the seat of the special faculty named, by the phrenologists, philoprogenitiveness, is not confirmed, though apparently supported by a few isolated cases of disease or injury to this organ. They are opposed by the fact of the slight connection of the cerebellum with the cerebrum, the proper organ of the emotions; by the teachings of comparative anatomy and physiology, as to the relative size of this organ in different animals; by the results of a wider investigation of the phenomena observed in disease in man; and, lastly, by those yielded by experimental researches in animals. Direct stimulation of one side of the cerebellum in guinea-pigs, has been found also to cause rotation, usually towards the sound side. By others, irritation applied to this part, is said to produce contractions, in many muscular organs, even in those of vegetative life, as, for example, in the stomach and cæcum. Vomiting, headache, squinting, affections of the pupil, disturbed vision, and convulsions, accompany morbid irritation of this organ, with evidences of disturbed movements, said to be due to interference with the muscular sense. (Lussana.) Inflammation of its membranes is unaccompanied by delirium; and, in cases of gradual softening of this organ, the intellect may remain unimpaired, even though it be almost entirely destroyed. Chronic disease of the cerebellum, however, is sometimes accompanied by unsteadiness in walking, without any symptoms of paralysis; in a few cases of disease of both hemispheres of this organ, backward movements have been noticed, and affections of one peduncle have been accompanied, in a few instances, by rotatory movements towards the diseased side.

Our general knowledge of the functions of the cerebellum being so scanty, it will be no matter of surprise that we are entirely ignorant of the relative importance and office of its several parts, viz., of the hemispheres with their lobes, the upper and lower vermiform processes, and the plicated sacs of gray matter in its interior, known as the corpora dentata.

The direct connection of the cerebellum with the cerebrum, is limited to the small superior peduncles, whilst it is much more extensively connected with the lateral columns of the spinal cord, by its large inferior peduncles; hence its anatomical connections seem to favor the views concerning its influence in the regulation and co-ordination of the muscular movements, rather than the supposition that it can exercise any important mental functions. Finally, it has been remarked that the gradually increased development of the cerebellum in the series of vertebrate creatures, from the fish up to man, coincides generally, with a greater and greater degree of complexity in the movements which they can perform, involving sometimes almost all the muscles of the body, and necessitating more extensive and perfect co-ordinating power. In what way this supposed faculty is exercised, is unknown. On the supposition that it co-ordinates the muscular movements, by being the seat of the *muscular sense*, some have suggested, that the impressions originating in the muscles, reach it through the restiform bodies, which are highly sensitive; moreover, it has been surmised, that the corpora dentata are the seat of this muscular sense, and that the hemispheres react upon impressions conveyed to them from those bodies. Yet it is difficult to suppose that the muscular sense, which appears to be only a modification of common sensation, has a special ganglionic centre. It has also been suggested, that the corpora dentata may be the seat of the muscular sense, and the hemispheres, of philoprogenitiveness. (Dunn.) It must be confessed that the functions of this organ are but imperfectly ascertained.

Functions of the Cerebrum.

The investigation of the special functions of this important part of the encephalon, is surrounded by great difficulties. We have already spoken of the large masses of gray matter situated deeply within the cerebrum, viz., the corpora striata and optic thalami, and the part they are supposed to play in the functions of sensation, and in the government of motion. But, in the superficial gray matter of the cerebral hemispheres, we recognize the anatomical organ which is physiologically concerned in the exercise of the faculties of *conscious* *attention*, *perception*, *ideation*, or the formation of *ideas*, probably also in *emotion*, and certainly in the operations of *memory*, *reason*, *judgment* and *will*. The hemispheres proper, appear, indeed, to be supplementary organs, superadded to the great nervous sensorimotor axis, not essential to it or to life, but acted upon by, and reacting through it. Their anatomical connections entirely favor this view.

The chief facts, in support of the opinion, that the brain is the corporeal organ, through which *mental* manifestations occur, are these: first, concussion, from severe blows, suspends all consciousness, and, with it, the higher mental operations; pressure, whether produced by a depressed portion of the cranium, by effusion of blood into its interior, or by effusions of a serous character, equally interferes with these functions; the effects of pressure have even been made evident in the case of persons whose heads have been trephined, by the temporary application of the finger to the exposed membranes of the brain; moreover, inflammation of the membranes covering the surface of the hemispheres, or of their cortical substance, usually causes delirium; in fatal cases of acute mania, the cortical substance is generally dark red; lastly, chronic destructive diseases of certain parts of the cerebral hemispheres, have been shown to be accompanied by impairment or loss of the mental faculties. Secondly, the relative size of the cerebral hemispheres, or, more accurately speaking, the relative quantity of the gray matter in them, presents a certain general correspondence with the mental endowments of the individual, the variety, and the species; of this, we shall give evidence in speaking of the brains of animals. The relative development of the several parts or lobes of the cerebrum, must here, however, be taken into account, and so likewise must the temperament of the individual, whether this be slow or quick. Thirdly, in cases of imbecility or absolute idiocy, the cerebral hemispheres exhibit the most remarkable defect in development of any part of the encephalon, although, as has been recently shown by myself, the corpora striata and optic thalami are involved in this deficiency, and even the cerebellum is also somewhat affected. Lastly, in no other part of the body, and in no other organ, is there such a corresponding development or deficiency, in proportion to the mental power, in both different men and in different animals, as in the hemispheres of the cerebrum.

Attempts were made, long before the more systematic teachings of phrenology, to locate certain faculties of the mind, in certain portions of the cerebrum. Thus, the intellect was supposed to be placed in the anterior region, the emotions or sentiments in the middle, and the instinctive feelings in the posterior part. By some, the memory also was located in the hinder part of the brain. The phrenologist teaches, probably correctly, that *memory* is exercised through every portion of the cerebral hemispheres; whilst he locates one powerful *instinct*, *philoprogenitiveness*, in the cerebellum; the lower *propensities* of animal nature, at the base and back part of the cerebrum; the *sentiments*, in the upper and middle part; the *observing* faculties, with the faculties of language and music, in the lower part and sides of the frontal region; and the so-called *purely intellectual* faculties of comparison and causality, in the upper frontal region. The chief argument in favor of any system of phrenology—for several have been proposed—is, that the science has been deduced from the actual observation of nature, that is, from a comparison, in very numerous instances, of the form of the skull, which is taken to represent the form of the cerebrum beneath it, with the propensities, moral feelings, and character, the acquirements, and endowments, of the individual. There is nothing irrational in the attempt to discover special organs in the brain for the performance of special functions of the mind; but the task is not so easy as Gall and his school have imagined. To their systems and method it has, indeed, been objected, that the instances of correspondence with the craniographic schemes projected by Gall and Spurzheim, and since modified and expanded by their followers, have been mainly collected by partisans of craniology or phrenology; that no systematic investigations have been undertaken, by other and independent observers, to test the actual frequency of those correspondences, or to detect any failures of such correspondence; that, in many instances, however, which have been noted, the most complete discrepancy has existed between the local development of the cranium, and the activity of the faculties or powers supposed to be exercised through the agency of the subjacent parts of the brain; and, lastly, that in reference to any given faculty, one such well-marked case of discrepancy, is sufficient to shake the system, as regards that faculty, to its foundation. It has, furthermore, not escaped the attention of the unbiassed physiologist, that, in spite of a general resemblance between the form of the cranium and that of the cerebrum beneath it, there are many difficulties, such as the relative projection of the frontal, parietal, and occipital eminences, the greater or less thickness of the cranium, and the variable size of the frontal sinuses, in different individuals, which render it almost, if not quite impossible, to determine accurately, degrees of local development of the parts beneath. Moreover, it has been shown by anatomists, that certain points or lines on the surface of the hemispheres—for example, the fissure of Rolando, and the convolutions in front of and behind it—do not invariably correspond with the same parts or lines of the cranial walls; but that, by excess or diminution of development, in these or in neighboring parts, they may shift their position backwards or forwards beneath the skull. It has also to be noted, that the convoluted gray cortical substance of the hemispheres, the supposed physiological seat of any force or faculty, which these parts of the cerebrum may exert, is not limited to that part of the cranial surface which is open to observation, nor, indeed, to the inner surface of the cranium at all; for it extends on each hemisphere, to the frontal and temporal fossæ, at the base of the skull, and even to the upper surface of the tentorium; and it likewise sinks deeply into the longitudinal fissure, quite away from the skull itself, and also into the Sylvian fissure, at the bottom of which, it forms the central lobe, or island of Reil, a part completely concealed between the overlapping edges of the frontal and parietal lobes. Lastly, no external cranioscopical observations can determine the relative complexity of the cerebral surfaces, nor the relative thickness of the gray matter. These facts, together with the utter absence of any coincidence between the boundaries of the convolutions and the craniographical mapping out of the so-called *organs* of the phrenologist, have led the most learned and influential anatomists and physiologists to demur to the system originated by Gall and Spurzheim. Nor is the catalogue of presumably *distinct mental* faculties, enumerated by the phrenologists, more satisfactory to the modern school of metaphysicians. Hence, whether the subject be regarded from a physiological or from a metaphysical point of view, although it may be true, yet not established, that different parts of the cerebral hemispheres exercise certain special mental functions, still it is by no means determined, either what those distinct or primal faculties or powers may be, much less the locality or organs, in or by which they are actively exercised in the body.

The first noteworthy observations, made in cases of disease of the cerebral hemispheres, tending towards a determination of the locality of any particular faculty, have been those collected by M. Broca, in reference to the faculty of *language*, which, according to him, has been noticed to have been lost in several adult persons, who, after death from paralysis, were found to have had *softening* of the upper and posterior part of the frontal lobe, in front of the fissure of Rolando. It is a singular, and hitherto quite unexplained fact, that, in these cases, the injured part was always on the left side of the cerebrum; and Dr. Hughlings Jackson has since shown that this is almost an invariable rule. Much further observation is needed to clear up this question, and it is yet premature to conclude that the organ of language is situated in the locality found in these cases to be diseased.

Experiments made upon animals, with the view of determining the special functions of the cerebral hemispheres, throw only a most general light upon this subject. The first great and fundamental fact to be noted is, that the cortical substance of the cerebral hemispheres can hardly be the seat of sensation, for it is itself insensible. Animals exhibit no signs whatever of pain, and no muscular contractions in either the muscles of animal or vegetative life, when the hemispheres are superficially pricked, pinched, or cut; and even in the human subject, injury to this part of the brain, or removal of portions which protrude after accidents to the head, does not cause local suffering, even though the consciousness be perfect. Neither does injury to these parts, inflicted purposely on animals, or accidentally on man, cause any convulsive motion. Nevertheless, though itself insensible, this cortical hemispheral matter is believed to be the place where sensations become perceived, *i. e.*, referred to their external causes, where attention is exercised, where ideas are formed, and emotions are excited; where memory retains its impressions, and where the will originates. For in animals, when the hemispheres are mutilated, the cerebral functions are disturbed; and when they are removed, those functions are suspended or destroyed. Thus, when one hemisphere is removed, there is produced temporary feebleness of the opposite side, with a permanent blindness in the opposite eye. After partial removal of both hemispheres, stupor is produced; but there soon return evidences of sensation, and of much muscular power. But when both cerebral hemispheres are completely removed, a kind of stupor exists; the animal remains in one attitude, and seems incapable of originating any independent movement. It still, however, retains the power of reaction, or reflex motion, on the application of external stimuli; for when the cerebral hemispheres of a pigeon are removed, leaving the optic thalami and optic lobes, besides the reflex contraction of the iris and closure of the eyelid, on the approach of a lighted candle, the bird follows the light with the head; so likewise, when the brain of a rabbit, including the optic thalami, is removed, it will withdraw its leg when it is pricked, and cry if its whiskers be pulled. But these latter movements are not positive evidence even of conscious sensation, much less of perception and will; they are, almost certainly, purely reflex, performed on the same principle as the simpler reflex movements, but possessing a more complex character; they are probably entirely unaccompanied by perception, and even if they be associated with any sensation, this is probably of a very feeble or obscure kind. Even the pigeon, when deprived of the hemispheres only, as above mentioned, though it may see objects, runs up against them, apparently from loss of perception and memory.

The cerebral hemispheres have been removed in birds, chiefly in pigeons (Longet), which, by artificial feeding, have then been kept alive for months. Birds so treated, sit still, as if asleep, with the neck retracted, the wings closed, and resting on both feet. When pushed, or when the foot is pinched, they seem to awake, to shake their body and feathers, open the eyes, advance a step forwards, and then relapse into their state of slumber. If dropped in the air, they spread out their wings, and even fly up, but strike against objects, and soon fall to the ground, from which they do not attempt to rise again. Sometimes they wake spontaneously, and prune their feathers. The eyes are still sensible to light, the pupils contracting; the eyelids are not closed at the approach of a candle, but some signs of uneasiness are manifested, and the bird follows the light by movements of the head. In a case observed by Malacorps, the pigeon was not affected by sudden exposure to strong light; but it appeared to seek out the light parts of a dark place; and was readily roused by slight noises. By Longet, however, noises were found to produce no effect, but, when very loud, caused, at the most, the animal to start; but this might be simply due to the mechanical shock. If the toes be touched, the foot is drawn away; and on repeating the irritation, it may be withdrawn under the wing, and the bird remain standing on one foot without loss of balance; if now, the other foot be irritated, it withdraws this, and puts out the opposite one. If ammonia be held to the nose, the head is violently shaken, and the bill is scratched with the foot. The bird can no longer pick its food; when this is placed in the bill it remains there; but when put on the back of the tongue, it is swallowed.

Similar experiments have been made on quadrupeds, with corresponding results, dogs no longer recognizing their master. All the phenomena seem to show, that not only the movements, but even combinations of movements to certain ends, occur after removal of the cerebrum; the state of the animals, however, is like that of dreaming, in which the acts are not accompanied by distinct perceptions of external objects, though by an imperfect consciousness. As regards sensory impressions, their condition is precisely similar, indicating a feeble or imperfect persistence of conscious sensation. This result sufficiently proves that the cerebral hemispheres are not the sole seats of consciousness, if, indeed, they are at all concerned in mere sensation. The loss of conscious power in such experiments, may not depend on any of it being, as it were, resident in the hemispheres, and so lost with them, but on the shock to the real sensory ganglia, caused by opening the cranium, and by exposure of these parts, loss of blood, and general depression of the remaining vital power. The movements of the animals are probably reflex, but of a higher kind than those performed through the cord and medulla: thus, a decapitated bird cannot, like the bird from which the cerebrum has been removed, stand on one foot, nor is the foot withdrawn beneath the wing, but it exhibits only convulsive resisting movements; it can neither walk, fly, nor prune its feathers, which are co-ordinated acts, governed by the cerebellum, and by the pons and other central parts at the base of the cerebrum.

In man and animals deformed by monstrosity, in which the cerebral hemispheres are especially defective, or even absent, reflex phenomena similar to those already mentioned (p. 294), are observed; for example, they may suck, swallow, and even cry, but they present no manifestations of any perceptive or other mental quality. That they may have sensation in a feeble degree is probable.

Disease of *one* hemisphere in man, so extensive as almost to destroy it, has occurred without any disturbance or diminution of the mental faculties; but when both hemispheres are seriously implicated, such phenomena are always manifested. Slow distension of the hemispheres, by an accumulation of cerebro-spinal fluid in the ventricles of the brain, does not much impair the action of this organ. All sudden injuries, even if slight, act severely as shocks; but slow suppuration, for example, has less effect. Inflammation and chronic disease of the gray or cortical matter, are usually accompanied with excitement or lowering of the mental faculties, whilst changes in the white or medullary substance, more frequently cause torpor, and loss of voluntary control over the muscles.

Of the cerebral hemispheres, it may therefore be said, that, by physiological experiment, we have proof that sensations may perhaps be *consciously felt* without them, but that they are certainly concerned in the *perception* of sensations, and in the origination of the volitional motorial stimulus or will. It would also seem, on general grounds, that their integrity is essential to the manifestation of that chain of mental acts which may be said to intervene between mere perception and the exercise of the will—that is to say, ideation, memory, association, and the reasoning processes. As to the emotions, the supposition of their association with some action of the cerebral hemispheres, rests only on general probability.

The hemispheres appear, however, to be the medium by which, through the channels of special and common sensation, the mind is brought into relation with the outer world, and reacts, through the motor paths, consciously and purposively upon it. This conscious action, which is, in a certain sense, reflex, is intelligence in action, and, as a rule, is proportionate to the size of the cerebrum. It gradually diminishes in the descending animal scale, in proportion to the relative decrease of the size and complexity of the brain in comparison with the size of the body. The proportionate weight of the cerebrum is not here the only fact to be considered; but also, first, the presence and degree of development of the convolutions, which serve to increase the extent of the gray matter, and, secondly, the thickness of the cortical gray substance which follows the convolutions. The relatively larger number of the transverse commissural fibres, in the brains of the higher animals, and especially of man, is probably also one element of their superiority. The uses of these commissures are not known, further than that they must serve to associate physiologically, the opposite halves of the brain. Deficiency of the corpus callosum has been found to be accompanied with want of intellectual power.

From the anatomical fact already mentioned, that the fibres, ascending from the cord and medulla oblongata along the peduncles of the cerebrum, pass no higher than the gray substance of the optic thalami and corpora striata, which bodies are connected with the gray matter of the cerebral hemispheres by a distinct system of ascending or radiating fibres, and from other considerations, it is probable that the only path of communication between the cerebrum and the outer world, is through that great sensori-motor nervous centre, which is composed of the large masses of gray matter found in the base of the brain, cerebral peduncles, pons Varolii, and in the medulla oblongata, and spinal cord. Even the volitional movements, though dictated by impulses originating in the cerebral hemispheres, are probably excited by stimuli proceeding directly from the sensori-motor nervous axis. In accordance with this view, the psychical acts, consequent on sensation, have been thus localized: a sensory impression, reaching the conscious sensorium or sensory portion of the sensori-motor apparatus, produces therein a sensation; this sensation, exciting in its turn the cerebral hemispheres, is supposed there to give rise to an idea; the idea, if associated with a feeling of pleasure or pain, becomes an emotion; and such ideas and emotions, when subjected to the intelligence or reason, lead to volitional determinations, or acts of will, which may either produce or restrain particular movements, or may govern and direct the processes of thought. (Carpenter.) The exercise of the will on the voluntary muscles, is also believed, as already mentioned, to be indirect—that is, by actions originating in the hemispheres, and operating on the sensori-motor ganglionic apparatus, at and below the base of the cerebrum, which apparatus then excites the motor nerves. Admitting the correctness of these views, it might be said that the fibres which are known to connect the optic thalami with the cerebral gray matter or cortical substance, are ascending or radiating fibres; whilst those which connect the corpora striata with the same parts, are descending or convergent, though anatomically, all may be considered as either radiating or convergent. The term "*nerves of the internal senses*," applied to the white fibres of the hemispheres, by Reil, expresses the general notion that they are concerned in offices of conduction related to the exercise of the emotional and intellectual operations. In further proof of this, it has been remarked, that the will determines only the performance of a given act. or the accomplishment of a certain end or purpose, not the chain of individual and combined movements necessary to arrive at such results. The mind is ignorant of the anatomical positions and connections of the muscles which it employs, or even of their existence; and this is equally true, whether an act be complex and effected by many muscles, like one of the movements of the upper limb, or simple, and performed by a single muscle, as occurs in raising the upper eyelid, or turning the eyeball to one side. In either case, the act is performed by willing a result, not by willing the muscular contraction. The regulation of the muscles of the larynx, for the production of the various vocal tones, is also similarly accomplished by the will, not directed to the laryngeal muscles, but to the purpose of producing a definite note, guided by the sense of hearing. The general fact, that most of the automatic movements performed by muscles of animal life, such as those of laughing, yawning, coughing, sneezing, winking, and so forth, can be imitated voluntarily, also favors the conclusion, that the motor apparatus *immediately* exciting the motor nerves is, in the two cases, identical. There are undoubtedly, indeed, voluntary movements, which may become, by the force of habit, automatic; and many ordinarily automatic movements may be suggested through ideas, or imitated by the action of the will; both sets of facts would therefore favor the conclusion that the nervous apparatus immediately directing the movements of the muscles, is the same, whether the act itself be automatic, ideational, or volitional. Thus, coughing and sneezing may be imitated voluntarily; yawning, by seeing others yawn; the convulsions of hydrophobia, by looking at bright objects suggesting the idea of water, or even by hearing water spoken of; and, lastly, vomiting may occur from the remembrance of nauseous tastes, or of the disagreeable feelings of seasickness. On the other hand, the action of walking, or even those more complex movements which are performed in playing on musical instruments, may, as already mentioned, become habitual or automatic.

Psychical Functions of the Nervous System.—Mental Faculties of Man.

Whether the mind be regarded as a single entity, distinct from the body, or whether the psychical manifestations or mental processes be viewed as the mere result of changes in the nervous substance of the cerebrum, it is certain that the brain is the corporeal organ through which those functions are performed; for, as we have seen, in order to give rise to those phenomena which we are accustomed to designate mental, either external or internal influences or stimuli must operate upon and excite that organ. Moreover, disturbances in its condition, and interruption of its functions, are attended with essential disturbances in, and cessation of, the psychical acts.

The fact, already mentioned, that, in the ascending scale of animals, the brain is gradually more developed as the mental powers increase, justifies the inference, that the superior mental endowments of man, as compared with those of animals, are related to those parts of the nervous system, the extraordinary development of which distinguishes man structurally from animals.

The impressions transmitted through the sensory organs and their sensory nerves, to those parts of the brain, whichever they may be, which constitute the *sensorium*, excite the *consciousness* and produce *sensation*. Sensation is the simplest psychical process, and sensations are, so to speak, the sources of all further mental activity. For the occurrence of temporary sensations, excited from without or from within, mere consciousness alone is sufficient; but when such sensations are to be rendered useful, as the subjects of succeeding mental operations, an internal active process is essential, viz., that of *attention*. Without this condition, impressions may sometimes be produced, and yet their effects on the consciousness may remain completely unnoticed. The sensory impressions, when realized through the attention, probably by aid of some simultaneous changes in the cerebral hemispheres, are then, by the act of *perception*, a far higher mental process, referred to their proper external causes, and thus successions of so-called *ideas* are formed. The formation of such ideas has been named *ideation*. Now, an idea may be transitory; but, on the other hand, it may also leave behind, probably in connection with some deeper changes in the nervous substance, a more permanent impression, and, by some occasional cause, by association, or, after practice, by the force of the will, it may again be called into existence, and this process is aptly named *recollection*, and the faculty by which it is accomplished, *memory*. These ideas constitute the materials of further *thought*, *i. e.*, of *association*, *comparison*, and *combination;* and hence arise, amongst other notions, those of the distinction between the body or corporeal frame and the outer world, or what are sometimes erroneously designated the *subject* and the *object;* also such notions as repetition, mass, and the sequence of events.

The higher animals are also capable of forming such ideas, and can compare and combine them in the act of *thinking*, so as to attain certain notions, and to acquire a given amount of knowledge and experience. But the sphere of this knowledge is limited, the ideas on which it is based are simple, and the notions formed are what are termed *concrete;* whilst the actions which follow, still refer merely to the conditions of their individual life, such as the obtaining of food, the avoidance of danger, pain, or injury, and the satisfaction of impulses which tend towards the maintenance of the species. By means of education and special training, a wider range of ideas and notions—still, however, of the concrete form—may, with time and labor, be imparted to, or aroused in, certain animals; but these are all extinguished with the individual, and are lost for the species. At the same time, certain special instincts, capable of cultivation, which are in no way due to processes of reason, and are certainly not the *results of teaching*, but rather *of primary impulses*, originating in the organization and nature of the individual animals, may be trained, and strengthened, and so transmitted, in the form of *habits* to the young, as is seen in the case of certain breeds of dogs.

In the human mind, however, besides the perception of simple concrete ideas, and the formation of concrete notions, *abstract* ideas arise by the further mental process called abstraction, and sometimes *conception*. Not merely is the outer world perceived by man, and recognized as an existence external to himself, consisting of objects and forces, differing from each other, and having certain mutual relations; but he can form abstract conceptions concerning himself, even concerning his mind, as distinguished from his body, thus reaching to the real *subjective* and *objective* distinctions of the metaphysician; for, in the estimation of the latter, even the body is objective to the real subjective "ego," or "self." He can likewise form similar conceptions concerning the outer world, the properties of objects, the causes of those properties, the nature of matter and force, the laws of the universe, and so forth. Moreover, he can proceed to reflect and reason upon these abstract ideas and notions, as yet further and independent objects of thought. The higher animals, then, have intelligence, and *understand;* but man alone is gifted with the power of forming abstract conceptions, and again considering these; in other words, he alone possesses the attributes of *pure reason*. Thus, an animal, as already said, may attain to a notion of what is hot or cold, pleasant to the taste, or painful to the touch, of the repetitions of objects, of mass, and sequence, but it does not, like man, rise to a conception of *temperature*, *taste*, or *pain*, of *number*, *quantity*, *space*, and *causation*, apart from facts, and from its concrete ideas and notions of experience; but, beyond this, man is enabled, by his faculty of *abstraction*, to form the higher abstract ideas, and purely psychical notions or conceptions; proceeding step by step till he arrives at notions, dim it may be, of an infinite past, an infinite future, a first and sustaining cause, a Creation and a Creator, and of the inevitable relations of his own nature to the great plan of Providence.

The *instincts* of animals are *innate impulses*, manifested in purposive actions, dependent, not on imitation, or habit, or reason, but on the very nature and *organization* of the animal itself, which is endowed with certain desires and fears, and acts so as to satisfy the former, and allay the latter. As a rule, these are perfect and uniform in all individuals, and practically immutable in the species, are uncontrolled by reason, or by an abstract desire for advancement, and constitute, indeed, the preponderating motives, or governing causes, of the actions of animals, even of the highest mammalia. In some of them, however, there is seen, even in the wild state, occasional evidence of cunning, which implies a certain exercise of the understanding, and a sagacity which can only be the result of intelligence; but the end to be gained, is still the gratification of some animal want. Man, likewise, is actuated primarily by his instincts in all he does; these are radical parts of his mental constitution. Many men, both in civilized and uncivilized communities, remain, like the animals, mere creatures of instinct; and amongst all men, these common instincts form the basis of their general life; the instinct of self-preservation, and those impulses which lie at the foundation of society and of the domestic relations are the most powerful. But these and the subordinate instincts and desires are variable in *degree* in different men, and they are controllable by *reason* and by *will*. Hunger and love are the momenta of human action; but man need not steal, nor yield to the suggestions of passion. Hence his liberty, his free-will, and his responsibility. As consequences of this freedom of will, to do or not to do, man's mental and moral nature is more plastic, more expansible, and more improvable, than that of animals. Animals may be trained and become obedient to man, probably from fear of punishment, or expectation of reward, occasionally perhaps from emulation; they may be taught to do this, and not to do that; but they can have no abstract conception of right or wrong. Man, however, undoubtedly may act irrespectively of personal motives without fear of consequences, regardless of applause or gain, and frequently at the cost of self. Animals obey a master, but even then without a notion of obedience in the abstract; but man obeys his judgment, knows what is obedience, and, moreover, has the abstract notion of *rectitude.*

In the contemplation of *abstract right* and *wrong*, as applied to his own actions, man feels his imperfections, but also perceives his own capacity for advancement and improvement, both physical, intellectual, and moral. In the interests of himself and of his race, he desires this advancement. By his intellectual powers, he not only inquires into causes and effects, in natural phenomena, but, by the application of his knowledge, through force of will, ending in invention, he renders the knowledge he has so obtained, useful to his fellow man, and to his posterity. Moreover, he desires and loves knowledge for its own sake, or for the pleasure it affords him, as a means of insight into the works and phenomena of Nature. In the sphere of morals, the desire for improvement is also a characteristic of Humanity, considered in the abstract, though it may be lost in the individual man; it has been even regarded as a Human *instinct.* But the standard of perfection conceivable by man, is felt to be beyond his actual reach; and, if all instincts have an object, this also must have its aim, to be attained, if not in a material, in a spiritual state of existence.

General Summary of the Functions of the Cerebro-Spinal Nervous System.

Having now described, in detail, the offices of the several parts of the cerebro-spinal nervous system, and having stated the experimental and other facts, on which our yet imperfect knowledge of those functions is based, it may be useful to point out, by way of general summary, the parts concerned in the exercise of each of those leading functions.

Psychical faculties.—There is reason to believe, that all the mental phenomena, properly so called,—commencing with perception, and passing on to ideation, memory, reasoning, and volition, also including perhaps the emotions, and, if we can regard it as a distinct human faculty, the power of employing spoken or written signs or symbols, to express ideas and notions, or the faculty of language,—are exercised or manifested fundamentally, through the agency of the cerebral hemispheres, especially through the action of the gray matter covering those hemispheres. All these faculties are injured or lost, from sections, injuries, diseases, or destruction of those parts.

Sensation.—Mere sensation, without the distinctness and memory associated with the higher faculties of attention, perception, and ideation, appears to have, for its seats or centres, the olfactory lobes and some of the gray masses at the base of the brain, at all events, the optic thalami, and corpora quadrigemina, and also some of the gray matter in the cerebral peduncles, the pons, and the back part of the medulla oblongata. The olfactory lobes appear to be the centres of the special sense of smell. The visual sense has apparently for its centres, the corpora quadrigemina with the back part of the optic thalami; the office of the corpora geniculata, in regard to vision, is unknown. The sense of taste resides in the gray matter of the upper part of the back of the medulla oblongata, and the sense of hearing, still lower down, in the same part of the great nervous axis. General or common sensibility is probably diffused through all the gray matter from the base of the cerebrum downwards, at least to the lower part of the medulla oblongata. Whether it should be regarded as extending also down the spinal cord, whilst this remains in connection with the encephalon (an opinion entertained, amongst others by Pflüger) may well be doubted, if not denied; for, owing to the condition of things, it cannot be proved, and the retention of excito-motor power, with the cessation of sensibility, which necessarily follow the severance of the cord, are quite explicable on the hypothesis that it is merely a conductor of sensory impressions upwards to the encephalon. As to the special seats or centres of the tactile sense, of the sense of temperature, of the common sensibility to pain, and of the muscular sense, the latter of which, however, is supposed by some, to be seated in the cerebellum, and as to the seats of those other and more vague sensations belonging to the vegetative or nutritive system, such as hunger, thirst, nausea, want of breath, &c., we are quite ignorant of their exact locality, although there may be special centres devoted to each or to some of them.

Voluntary motion.—The seats or centres, in which the volitional motorial stimulus originates, are certainly the cerebral hemispheres; for the will is completely annihilated, when these are removed, or when their integrity, or power of action, is otherwise interfered with. Whilst, however, the will to act arises in the cerebrum, the co-ordination of the various movements of the body, seems to require for its accomplishment, the direct or indirect co-operation of the cerebellum.

Involuntary motion.—Involuntary motion includes movements suggested by ideas, *ideo-motor* (Carpenter), *emotional* movements, *instinctive*, or *sensori-motor* movements, which are reflex movements of a more general and more highly co-ordinate character, and are accompanied by sensation; and lastly, the more *simple reflex* or *excito-motor* movements, which are not necessarily accompanied by sensation; and which include some governed by the spinal cord, and others regulated, as we have hereafter to describe, by the action of the sympathetic system.

The *ideo-motor*, or ideational movements, such as those of laughter, or sadness, produced by ideas passing through the mind, must have their organic centres in the cerebral hemispheres; so, too, the co-ordinated movements are performed under the influence of ideas arising in the mind, during reverie, dreaming, and somnambulism, when consciousness is absent.

The *emotional* movements, such as the sobbing of grief, or the smile of joy, must likewise have the cerebral hemispheres as their centres of origin, if we regard those hemispheres as the seats of the emotional faculties themselves; and not, as some imagine, the ganglia at the base of the brain.

The *instinctive* or *sensori-motor* movements, such as those of sucking, clinging, or attempting to retain the balance, winking the eyes, and many others, manifested even in the new-born infant, appear to have their seat in the great centre of sensorial and motorial excitability, extending from the corpora striata, optic thalami, and corpora quadrigemina, through the cerebral peduncles, the pons and medulla, and down through the whole length of the spinal cord; for such movements continue after the cerebral hemispheres have been removed, in animals, and occur in the human infant, in cases of monstrosity, in which the upper part of the hemispheres is wanting. These instinctive movements merely differ from the ordinary reflex acts, in being associated with sensation, in being more complex, and in involving a greater extent of the nervous and muscular apparatus.

The simpler *reflex*, or *excito-motor* acts are also performed through the agency of the same motorial gray centre, extending from the corpora quadrigemina down to the lower end of the cord; but they involve, in their performance, smaller portions of that long chain of gray nervous substance, and do not necessarily excite its sensorial portions.

Of the reflex movements generally, whether excito-motor or sensori-motor, some are concerned in regulating the functions of the organs of the *senses*, such as those which govern the condition of the iris, the ciliary muscle, and the muscles of the tympanum. The *preservative* reflex movements are illustrated by the winking of the eyelids to moisten the eyeballs, and relieve the retinæ temporarily from the effects of light; and by the acts of sneezing excited by impressions on the retina, or on the nasal mucous membrane, for the expulsion of noxious matter from the nose, of coughing to expel foreign bodies, or mucus, from the larynx, or air-tubes, and of vomiting, whether induced by disagreeable odors, tastes, or offending matters in the stomach, or even by sea-sickness. The shutting of the eyelids and the closure of the glottis, or aperture leading into the air-passages, for the prevention of foreign bodies entering the eye, or of poisonous gases entering the lungs—are further illustrations of protective or conservative reflex acts.

The act of deglutition, and the respiratory movements, are also reflex; and so are the irregular or spasmodic inspiratory movements produced by sudden application of cold water to the skin. Still more simple spinal reflex movements are, the snatching away of the hand, or the sudden lifting up of the feet, from unexpected causes of irritation. Many other illustrations may also be adduced of such reflex movements; such are, for example,—belonging to muscles of *animal* life—the starting on hearing sudden, loud noises, probably also the movements of walking in sleep, or in the state of somnambulism, though these imply also a great power of co-ordination; even, to a certain degree, the ordinary unconscious walk of persons absorbed in thought;

the performance of complex, though habitual, movements on musical instruments; other habitual, and all the instinctive movements of men and animals; and, as the results of morbid or exalted action, the rolling of the eyeball and spasm of the eyelids, in irritable states of the retina, and the spasmodic movements of hydrophobia, hysteria, chorea, epilepsy, and tetanus. In the sphere of *vegetative* life, may further be mentioned, the action of the cardiac, and perhaps of the pyloric, circular fibres of the stomach; and certain general movements of the stomach and intestines; yawning, and sighing, as the results of fatigue, or of some oppression of the respiratory organs; and even laughter, when caused by tickling, and not by ludicrous ideas, or pleasurable emotions.

The office of the great excitable nervous centre of the reflex actions may be said generally to be to excite and regulate all the muscular movements necessary for the continuance of organic or vegetative life. It has been well remarked that it never sleeps. (Marshall Hall.) Whilst various movements, immediately necessary for the preservation of the organs, or of life itself, are thus performed, those which, like the prehension of food and others, are only more remotely necessary, have more or less of reason and will associated with them. In this latter case the afferent impressions from without ascend to the cerebrum and operate by inducing ideas, emotions, reasoning processes, and volition; and this is the ordinary case with man. If, however, their ascent to the cerebrum be arrested by sleep, coma, the influence of narcotics, or the actual destruction of the parts by disease; or even if the powers of the attention be not directed to them, then purely sensori-motor actions ensue, as is the normal case in those of the lower animals which possess no higher nervous centres than these sensory ganglia. Extremely powerful stimulation of these parts in man is also followed by sensori-motor acts, even when the cerebral functions are in a state of perfect activity. The actions of infants generally exhibit the same absence of cerebral government, being mostly sensori-motor, as, for example, the act of sucking. Lastly, in idiots the predominance of the sensori-motor over the rational acts is very obvious.

The particular parts of the great excitable centre which are called into action in these several reflex movements, may be inferred from the attachments of the afferent and efferent nerves engaged; that is to say, of the afferent nerves which receive the external stimulus and convey its effects to the nervous centre, and of the efferent nerves which supply the muscles thrown into action. These details will be referred to under the description of the functions of the several organs concerned in these reflex movements.

The involuntary reflex movements whether complicated or simple in their nature, require no previous education or instruction for their proper performance; and thus their due occurrence is provided for independently of any effort of the intelligence and the will, so that the mind is free to perform its own workings, whilst the care of the body is intrusted to other powers resident in the system which induce no exhaustion of the volitional power. Nevertheless some of these reflex movements, whether ideational, emotional, instinctive, or simply preservative, may be controlled by the will, and may also be imitated under the influence of the will; for we may stop laughter or sobbing, or arrest for a time the respiratory movement; or, on the other hand, we may imitate or perform these movements through voluntary efforts. A certain number of these movements, however, are placed entirely beyond the direct control of the will, as the movements of the iris and the last stage of deglutition.

The higher reflex movements, viz., the ideational and emotional are ordinarily accompanied by consciousness and sensation; but ideas occurring in dreaming and like states of unconsciousness also give rise to similar movements, which therefore furnish examples of cerebral reflex acts without conscious sensation. The other reflex movements may also be accompanied by sensation, as, for example, the act of deglutition, the acts of coughing and sneezing, and that of snatching away the hand from a hot body. But the lower reflex movements, whether complex or simple, are not necessarily attended with conscious sensation, and are certainly quite independent of it, as we see in the movements of the iris; also in instances of paralysis of the lower limbs, in which the reflex movements still continue; and likewise in the performance of deglutition, and of respiration in a state of profound coma, and of respiration under the influence of chloroform, or in the condition of sleep, both of which have the effect of perfectly suspending conscious sensation. This independence of sensation on the part of the reflex acts necessarily diminishes the fatigue that would be attendant upon their performance if they were incessantly brought before the mind as subjects of the faculty of attention.

There are certain movements, performed by man and animals, which are known as *automatic;* examples of these are met with not only in the involuntary but also in the voluntary muscular organs. The rhythmic movements of the heart are of this kind, and also those of respiration. But besides this, certain instinctive acts, and even the simpler or habitual acts of locomotion, have been regarded as automatic, or as simple reflex movements, performed without the agency of the will. In the cold-blooded vertebrata, and still more obviously in insects and myriapods, for example, simple progressive locomotion appears to be almost or entirely independent of volition; for decapitated centipedes will, if stimulated, run rapidly forward, will even raise their headless trunks over small obstacles, and force them persistently against more formidable ones; decapitated lizards exhibit similar, though less prolonged, movements. In the habitual movements of walking performed by ourselves, volition, and sometimes even consciousness, take but little or no part; and thus they become truly automatic. Many persons, moreover, as, *e. g.*, orators, actors, musicians, and particular handicraftsmen, acquire by habit, or necessity, the power of performing very special movements, without the continued aid of volition; such movements have been named *secondarily automatic*, and have been supposed to be accomplished through the sensori-motor, or even through the purely excito-motor, nervous centres. They are, indeed, reflex actions of a higher order than the reflex movements *natural* to every one, and might be termed *acquired* reflex acts, or acts of *unconscious volition*, which itself, viewed as a cerebral process, is a reflex act of the highest order.

In passing from the functions of the cerebro-spinal nervous system, to a consideration of those of the sympathetic nervous system, we shall find that this system also acts in a reflex manner, possibly solely and entirely in that manner, and that the reflex acts governed by it are quite involuntary, and, at least in health, independent of sensation.

Functions of the Sympathetic Ganglia and Nerves.

The structure of the sympathetic nerves, and their anatomical connections with the cerebro-spinal system, afford reasonable ground for the opinion, that this remarkably complicated part of the nervous system is, neither physiologically nor anatomically, to be considered as a mere portion of the cerebro-spinal nervous system, nor yet as a system independent of it; but that it is physiologically possessed of certain special functions, at the same time that it is, in many points, functionally associated with the cerebro-spinal system.

The nerve-fibres, whether white or ganglionic, and the substance of the ganglia themselves, are, like the nerves and gray centres of the cerebro-spinal system, *conductors* of the effects of impressions made upon them.

Doubtless, also, the nerves consist of both *afferent* and *efferent* fibres, some of the afferent fibres probably terminating in the sympathetic ganglia; whilst some undoubtedly proceed through the ganglia on to the cerebro-spinal centres, and some also perhaps pass from the gray matter of the sympathetic ganglia to the gray matter of the cerebro-spinal centres. The connections of the efferent fibres are certainly with the ganglionic gray substance of the sympathetic ganglia themselves; and most probably also, they have indirect or direct connections with the cerebro-spinal nervous centres. There is reason to believe further, that the gray matter of the sympathetic ganglia, can not only conduct the effects of impressions, but may also *transfer* and *radiate* them. This gray matter of the various sympathetic ganglia, is also considered by some to be the seat or centre of origin of *special* nerve force, and the whole sympathetic system to be, so far, independent. Lastly, the power of the sympathetic nervous system, perhaps the force originating in its ganglia, may be inhibited or interfered with by the superior force of the cerebro-spinal nervous centres.

The sympathetic nervous system, considered generally, has for its function the office of presiding over the viscera of the body, as its distribution implies. It has been named the *vegetative*, or *nutritive* nervous system, and sometimes, from its distribution, the *visceral* nervous system. From the fact, that its branches reach their ultimate destination, supported upon the large and small arteries, and since they may be traced likewise on to the arteries of the trunk of the body and of the limbs, it is probable that the greater part of the influence which they exert upon the viscera, and on other parts of the body, is exercised through a certain control over the muscular substance of the heart, and over the muscular coat of the arterial vessels. The sympathetic nervous system might be designated the nervous system of the vascular apparatus; its ultimate branches constitute the so-called *vasi-motor nerves.* We shall immediately see evidence of this control, and of the manner in which it appears to be exercised; and we shall find that, even in this function, it is more or less assisted by, and subordinated to, the cerebro-spinal system.

We may consider the special functions of this system, in relation to sensation, motion, nutrition, and secretion, and to the physiological connections between it and the cerebro-spinal system.

The sympathetic nerve, when the parts to which it is supplied, are in a state of health, does not appear to be *sensitive* itself, nor to transmit sensory impressions; for there is no feeling in the parts to which these nerves are distributed, when they are in a condition of health. In disease, however, cramps and other pains, sometimes of a most acute and depressing character, are experienced in them; the effects, as one would say, of an exaltation of the common sensibility without any tactile sense. In experimental irritation of the sympathetic, pain is produced, the amount of which seems to vary under different circumstances. In all cases, the stimulus must be powerful enough for the effects of the impression to be transmitted to the cerebro-spinal system, and reach the centre of common sensation; for the substance of the sympathetic is itself insensible, and the sensibility of parts supplied by its branches only, must be due to its connection with the cerebro-spinal system. Whether the effects of such impressions, are conducted by afferent fibres, running direct from the sympathetic nerves to the cerebro-spinal nerves, or whether they are first conducted to the sympathetic ganglia, and thence indirectly, by fibres originating in the gray matter of the sympathetic ganglia, is not quite certain. If the former be true, the reason why the parts supplied by the sympathetic nerves, are insensible in health, must be, because the number of afferent cerebro-spinal fibres in them is so few; if the latter view be correct, the insensibility of these parts in health, must depend on the interruption, or cutting off, of the sensory impressions at the ganglia. Again, the increased excitability, produced in disease, either compensates for the paucity of the afferent fibres, or else causes the effects of the sensory impressions to be transmitted, with greater force, through the ganglia.

In regard to the control of the sympathetic nerve over the *motions* of the parts to which it is supplied, it is in the first place, important to note, that this system is never the path of the voluntary motorial stimulus, the movements of all the parts being strictly involuntary, or entirely beyond the control of the will. Thus the movements of the intestines, in urging onwards their contents, are reflex, and excited through the sympathetic nerves, by the mechanical stimulus of the food.

That the sympathetic nervous system influences the movements of the parts to which it is supplied, is proved by irritation of the nerve, and by its division. Irritation of the sympathetic nerve distributed to the iris, causes that membrane to contract in its width, so that the pupil becomes dilated.

The *lenticular* ganglion of the orbit, is the centre which governs the nutrition of the eyeball, and through which the movements of the iris are accomplished; the sensory nerves of the eyeball, coming from the first division of the fifth, and the motor nerves from the third cranial nerve, pass through it, as elsewhere explained. The relative size of this ganglion, in animals, is proportionate to the activity of the iris, and to the general powers of sight; it is large in nocturnal animals.

Division of the sympathetic branch which connects the lenticular ganglion of the orbit with the superior cervical ganglion, causes immediate paralysis of the radiating fibres of the iris; and the pupil contracts, in consequence of the action of the circular fibres, which are governed through the oculo-motor nerve of the eye. On the other hand, galvanic irritation of the lenticular ganglion, or of the cervical or dorsal portion of the spinal cord, with which the upper cervical ganglion of the sympathetic is connected (provided, in the latter cases, that the shocks are sufficiently powerful), is followed by contraction of the radial fibres, and consequent dilatation of the pupil. Irritation of the cervical portion of the cord, produces protrusion of the eyeball; whilst section of the same, causes its retraction, and also gives rise to partial closure of the eyelids, to a forward movement of the nictitating membrane, and to a narrowing of the nasal and buccal openings; irritation produces the opposite effects.

Irritation of the nerves of the heart, affects the movements of that organ. Galvanism, applied to the cervical part of the sympathetic, to the superior thoracic ganglion, to the branches connecting it with the spinal cord, or to the cervical portion of the latter, determines a remarkable acceleration of the heart's beats; in the two latter cases, in a less marked manner. The diminution in frequency of the action of the heart, by a weak stimulation, and its complete arrest, by a strong stimulation of the vagi nerves, have already been mentioned, as well as the weakening effect of removal of the cerebro-spinal axis. The pulsations themselves seem, therefore, to be determined by some influence emanating from the sympathetic nerve, but their force is governed by the cerebro-spinal axis.

In the same manner, irritation of the splanchnic nerves, of the thoracic portion of the sympathetic, or of the dorsal region of the spinal cord, causes movements in the intestines, ureters, and bladder; but very strong galvanic shocks diminish the intestinal peristaltic action.

These movements, even when excited by stimuli applied close to the ganglionic centre, and performed by parts near this centre, always occur slowly, and not instantaneously and spasmodically, as is the case with movements excited through the cerebro-spinal nervous system; they are more or less rhythmical, continuing to be performed, for some little time, at regular periods of succession, and passing off slowly. When these movements become languid, or even have altogether stopped, they may be increased in activity, or entirely revived, by the fresh irritation of the sympathetic ganglia or nerves. These peculiarities of the reflex actions of the sympathetic, have been attributed to the modifying and diffusive influence of the ganglionic cells, through which they are supposed to be transmitted. (Fick.)

The influence of the *vasi-motor* nerves over the smaller arteries, is shown by dividing the sympathetic nerves distributed to any part, as, for example, in the neck of a rabbit, when the small arteries of the corresponding side of the face, and of the ear, become dilated, the blood collects in them, and accumulates, as is manifested by their dark red appearance and increase of temperature, and by the general exaltation of the vital powers of all the tissues: the temperature is sometimes elevated as much as 18° ; perspiration covers the skin ; the venous blood is brighter, and coagulates more quickly than usual. The retina becomes more sensible to light ; the pupil contracts, the eyelids are partially closed, the membrana nictitans projects, the eyeball is retracted, and a flow of tears takes place. The muscles are more irritable ; the rigor mortis appears more slowly, and lasts longer ; inflammation and the reparation of injuries, effusion of serum, suppuration, and absorption of extravasated blood, and the process of cicatrization, occur more quickly, and are more active. If now the upper portion of the cut sympathetic nerve be irritated by galvanism, the vessels again contract to their usual size, the parts assume their natural appearance and condition, and all the preceding phenomena are exactly reversed. These singular effects are more marked, if the cervical ganglia are destroyed. Other experiments likewise appear to exhibit the power of the sympathetic over the circulation, temperature, and vital properties of the tissues. Thus, division of the roots of the spinal nerves of the upper limb, before they leave the spinal canal, causes loss of sensation and motion in the limb, but no change of temperature ; whereas division of the large nerves of the limb, subsequently performed, is at once followed by a rise of the temperature of the part, certain fibres being then divided, which must have their origin directly in the sympathetic ganglia, or else must pass through them, from some distant part of the spinal cord. (Bernard.) So, also, increased vascularity and temperature of the lower limb, but no loss of sensation or motion, have been found to follow destruction of the lumbar sympathetic ganglia. But Schiff asserts, that the temperature of a limb is elevated, after section of the anterior roots only of its spinal nerves.

This control of the sympathetic over the calibre of the small arteries, is believed by some to explain its influence on the processes of *secretion* and *nutrition*. The former have been already mentioned, in speaking of the functions of the facial and fifth nerves ; but it may be added, that the flow of tears from pain, and the partial sweatings of one side of the face, after division of the sympathetic of the same side, are further examples of this influence. The sympathetic vasimotor nerves appear to act, by causing contraction of the vessels, so as to diminish their calibre ; and the dilatation which ensues on their division or exhaustion, not only increases the supply of blood, but also the permeability of the coats of the bloodvessels themselves. Division of the sympathetic nerve in the neck is, after a time, followed by opacity and ulceration of the cornea. The amaurosis, which is sometimes dependent on the irritation produced by intestinal worms, is explained by supposing that the nutrition of the retina is impaired, owing to the contraction of the vessels, causing a diminution of its supply of blood. It was found by Brown-Séquard, that when one hand was immersed in water at 32°, the temperature of the opposite hand fell, though that of the rest of the body remained unaltered; this effect he attributes also, to the diminution of the nutrient arteries, through the influence of the stimulus upon the vasi motor fibres of the sympathetic system, transmitted to the opposite, but corresponding, part of the body. Whether this effect is due merely to the diminished supply of blood, or partly to the resulting interference with the ordinary nutritive changes of oxidation, is uncertain. Ice, applied to one wing of a bat, causes, in like manner, contraction, or even closure, of the vessels of the corresponding point of the opposite wing. If a freezing mixture be applied to the ulnar nerve at the elbow joint in the living body, the two inner fingers, at first, become slightly colder, but their temperature slowly rises, till they are at length some 9° or 10° warmer than the three outer fingers, owing to paralysis of their vasi-motor nerves; the temperature of the three outer fingers is probably lowered, on account of the diminished quantity of blood in the radial artery, so that this, in part, accounts for the difference in temperature. Pressure of the finger behind the ramus of the jaw, produces phenomena, some of which are similar to those observed on irritating the sympathetic in the neck; others, however, are due to irritation of the pneumogastric nerves; *e. g.*, heat and tingling of the ear, difficulty of breathing, cardiac and gastric disturbance, and even dilatation, and subsequent contraction, of the pupil.

The real nature of the dilatation of the vessels, which ensues on division or paralysis of the sympathetic nerves, is uncertain; some maintain that it is active, and that just as the pneumogastric nerves serve to inhibit, regulate, or restrain the movements of the heart, so, in this case, some active dilating influence is the cause of the relaxation of the muscular coats of the vessels; according to others, however, the dilatation is passive.

It is remarkable, that movements similar to those already mentioned in the heart, the intestines, and in the coats of the small vessels, may be produced by irritation or division of certain portions of the spinal cord; those, in fact, with which the sympathetic nerves, supplying any given part, are connected; so that the influence of the sympathetic nerves on the movements of the heart, intestines, and coats of the arteries, would seem to be derived, in part at least, from the spinal cord and medulla oblongata, which are therefore *visceri-motor* and *vasi-motor* centres. This appears to be especially true of the heart and stomach. It is even supposed that the constant influence exerted by the sympathetic upon the smaller arteries, is owing to a stimulus conducted to those nerves, but originating in the cerebro-spinal axis. The same is said to be true in regard to its power over the visceral movements. Thus the lenticular ganglion of the orbit has been experimentally shown to be connected with the spinal cord between the sixth cervical and second dorsal vertebra, and also with the back of the medulla oblongata. The sympathetic nerves of the heart are connected with the cervical and upper dorsal region, and those of the intestines, with the lower dorsal portion of the cord. It is further supposed, that when, from any cause, the ordinary amount of stimulus, proceeding from the spinal cord to the sympathetic, is withdrawn, the vessels then dilate, as in the act of blushing, and under other conditions, contract, so as to cause pallor. But these phenomena are also dependent on the relative force of the heart's action, as in passion or fear. The movements of the viscera may also be affected, as shown by agitation of the heart, or by increased peristaltic action of the intestines.

Emotional movements may likewise be produced in parts supplied by the sympathetic nerves, and the stimuli which produce them must of course originate in the cerebrum or centre of the emotions. There is reason to believe that *ideas* even may act in a similar manner.

Instinctive causes, or like actions of the cerebro-spinal system, may produce effects upon associated parts, which must take place through the sympathetic nerves; as, for example, when the act of sucking produces an accompanying increase in the flow of saliva. The similar increased secretion of the lachrymal gland in shedding tears, affords evidence of an emotional stimulus affecting a gland through its sympathetic nerves; and the flow of saliva, at the thought of a coming meal, affords similar evidence as regards ideational stimuli. Indeed, such glands as the lachrymal and salivary glands, which act only at certain intervals, and are particularly affected by mental states, receive, besides sympathetic nerves, many branches from the cerebro-spinal system. But strong mental stimuli may also arrest the lachrymal secretion, as is well seen when a person is overpowered by grief; in like manner, the flow of saliva may be checked by strong emotions. It is probable that the gastric secretion is, like the saliva, also excited by mental stimuli; it has been seen to be rapidly secreted in fasting dogs, at the sight of food.

Of simple reflex acts, performed through the cords and ganglia of the sympathetic, we have numerous instances; and in these cases, too, we shall find that sometimes they are performed through the intervention of the spinal cord; though cases may be quoted in which the sympathetic must act altogether independently of the cerebro-spinal system. Thus, it is said, when the visceral nerves of the abdomen of an animal are powerfully galvanized, movements of the abdominal muscles are excited; and irritation of the frog's intestines or liver will also excite movements in certain voluntary muscles.

In the human subject, too, both the striated and non-striated muscles may be affected through the sympathetic nerves, for strabismus or squinting, convulsions in infants, and epileptic attacks in the adult, are sometimes caused by worms, or irritating substances, in the alimentary canal; moreover, a form of paralysis, known as reflex paralysis, and certain muscular symptoms, showing disturbance of the nervous system, are sometimes induced by disease or irritation of distant viscera, or of highly sensitive parts, such as the dental nerves; whilst colic and even diarrhœa frequently result from the introduction of irritant substances into the alimentary canal, and from the irritation of teething in infants. In the foregoing cases, it would seem that the fibres of the sympathetic system play an afferent part as regards the stimuli employed; and that the effects of the stimuli are conveyed to the reflex centre of the spinal cord, and thence act upon efferent fibres belonging to the cerebro-spinal system. But, in the second place, examples of reflex acts, performed through the sympathetic, quite independently of the cerebro-spinal system, are found in the case of those movements of the intestines, or of the heart, which continue after the trunks of their nerves are divided, or even after they have been entirely removed from the body. The apparatus through which the movement in such cases is excited must be the sympathetic nervous system. When, indeed, a stimulus is applied, under such circumstances, to a part of the intestine, or to a portion of the heart, the movement produced is not merely local, but is transmitted, or propagated, to neighboring parts; and, instead of producing only a single motion, as would be the case in a detached voluntary muscle, the movement is continued, and even follows the ordinary peristaltic or rhythmic character. The centres, through which the effects of the stimulus are thus extended beyond the immediate seat of their application, are the intrinsic or visceral ganglia, to and from which afferent and efferent fibres convey the effects of the stimulus, in the ordinary reflex manner. According to another view, these ganglia, during life, are the centres of a direct governing force, which regulates the movements of the parts, that is to say, a central stimulus originates in them, independently of the effects of stimuli conveyed to them by afferent fibres. The details of this subject will be found in the Sections on Digestion and Circulation, in the account of the movements of the heart and the intestines, and of their dependence on the nervous system.

As already stated, the movements of the heart and intestines, whether performed by reflex actions, governed through the sympathetic system, or by the action of direct centric stimuli, originating in the sympathetic system, and entirely beyond the control of the will, may be affected through the cerebro-spinal system, by exciting or depressing ideas and emotions. Lastly, experiments show that the sympathetic is so far dependent on the cerebro-spinal axis, that stimulation of certain parts of the brain excites movements in the muscles of vegetative life; and that, after destruction of brain and cord, the general sensori-motor functions of the sympathetic are lost.

Influence of the Nervous System on Nutrition and Secretion.

There is abundant evidence, which will be hereafter detailed in the Sections on the above-named subjects, to show that the processes of nutrition and secretion can be influenced through the nervous system. There is reason to believe that the part of the nervous system here specially concerned, is the sympathetic nervous system, experiments having shown that when the sympathetic nerves, supplying a part of the body, are divided, the nutrition of that part is immediately interfered with; and when the sympathetic nerves belonging to a gland are divided, its secretion is arrested. The reflex action of the sympathetic system on secreting glands is well exemplified by an experiment in which, when the œsophagus was divided, a large quantity of saliva was secreted, on injecting broth into the stomach. (Gairdner.)

The effects of division of the sympathetic, in causing dilatation of the vessels and congestion of any part by paralyzing the muscular fibres of the coats of the small arteries, which have already been noticed (p. 308), are supposed to offer an explanation of the mode in which the sympathetic nerves may influence the processes of nutrition and secretion, as observed in the increased flow of tears and saliva under certain circumstances; but besides that *indirect* mode of action, it appears probable that the nerves may, in certain instances, exercise a *direct* influence over the various chemical processes of nutrition and secretion (see *Secretion and Nutrition*). The function of nutrition would seem to be more intimately connected with the sympathetic than with the cerebro-spinal system; for it has been found that, in frogs, the nutrition of the parts to which the spinal nerves are distributed is much more impaired when these are divided after they have passed the intervertebral ganglia than when they are divided behind those ganglia. (Axmann.) In like manner, division of the fifth cranial nerve in front of the Gasserian ganglion leads to more rapid inflammation and consequent destruction of the eye than division of the same before it enters the ganglion. (Magendie and Longet.) Lastly it has been noticed that paralysis of both the sensory and motor roots of the spinal nerves is followed by greater disturbance of nutrition than when the motor roots only are implicated.

Bilateral or Double Action of the Nervous System.

In describing the nervous system we have repeatedly alluded to the strictly bilateral character of its anatomical construction; and in treating of its functions it must not be forgotten that it possesses a perfect physiological duality; and this fact, coupled with the decussating structures met with at certain points, and with the cross action of those parts from side to side, leads to certain curious results.

Thus, passing from below upwards in the cord, sensory impressions cross over to the gray matter of the opposite side, immediately through the whole length of the cord; whereas, the motor impressions pass from side to side in the medulla oblongata. In the cerebellum the cross effect is noticed in the rolling over or turning round of the animal on the opposite side to that on which an injury is inflicted; though this might depend either on stimulation or on loss of control of the muscles of the opposite side, or on a loss of power of the muscles of the same side; still there is a cross effect. In regard to the large ganglia at the base of the brain, similar cross effects are noticeable, injuries to the optic thalami or corpora quadrigemina affecting vision in the opposite eye. The decussations at the optic commissure also lead to remarkable results in reference to vision, which will be noticed in the Section on Sight. Above the medulla, in the pons, and in the peduncles of the cerebrum the cross effect is also manifested, both as regards sensation and motion; for the paths of both have already decussated lower down. Lastly, it is maintained that many of the radiating fibres of the cerebral hemispheres pass over from one hemisphere to the other through the corpus callosum; and, in any case, the two hemispheres, as well as all the other parts of the bilateral nervous centres, are closely connected together by commissural structures both gray and white.

In reference to sensation and motion, the action of a bilateral nervous centre is explained by the bilateral structure of the parts with which it is connected through its nerves; but the unity of the mind, that is of the conscious part of our nature, and its various reactions on the body, seeing that the brain is double, have constituted a perplexing problem to certain physiologists. Ordinarily both hemispheres probably act together, each part of the two being respectively associated by its commissural connections. But it has been shown that one is sufficient for the persistence of all the mental faculties, and of their determining influence on the body; for considerable portions of one hemisphere have been cut away by the sword or otherwise, and very much larger portions have been altered or destroyed by disease, and yet all the mental faculties have been preserved. These and other considerations have led to the adoption of the opinion that the mind itself has a dual action, and that it is possible that when two concurrent trains of ideas or thought pass together through the mind the cerebral hemispheres are acting differently or in a dual manner, though ordinarily they act together. (Wigan.)

Sleep.

Sleep consists in a temporary suspension of the functions of the cerebral portion of the nervous system. It may be defined to be a periodical rest of the organ of consciousness, as regards the outer world; so that this is no longer sensible to its ordinary stimuli. Sleep and the waking state have been described as the result of a kind of antagonism between the organic and the animal life; the functions of animal life, governed by the mind, enjoy from time to time, freedom of action, whilst at other times, they are repressed by the organic force acting in obedience to a law of creative nature. (Müller.) The cerebral hemispheres, and the sensory ganglia at their base, like all other parts of the body, undergo, in the exercise of their functions, a waste of tissue; hence they require rest, that new matter may be added to them, to compensate for the waste and disintegration of their substance. During sleep, however, all the functions of vegetative life continue to be performed. The pulsations of the heart, the circulation, the movements of respiration, the interchange of gases through the lungs and skin, and the chemical and mechanical phenomena which accompany digestion, absorption, secretion, and nutrition, pursue their course. The movements of the muscles concerned in these functions are, however, somewhat less frequent than during the waking state; thus the respirations become slower or fewer in number, though deeper; the beats of the pulse diminish in number. On the other hand, the action of certain voluntary muscles, as, for example, of those which roll the eyeballs upwards, is increased. The iris is contracted. The various excretions are less abundant; but the quantity of phosphoric acid separated by the kidneys, is said to be somewhat increased. The animal heat is also lowered, hence the sensation of cold which is often felt on awaking. The quantity of blood in the vessels of the brain, and the rapidity of its circulation, are both much diminished. (Durham.) This observation is contrary to the old opinion, that sleep was the result of a turgescence of the vessels of the brain; but it is confirmed by the state of the retina or expansion of the optic nerve, which has been found, by aid of the ophthalmoscope, hereafter described, to be paler, and less vascular during sleep. (Hughlings Jackson.) It has been suggested, that the bloodvesssels of the choroid plexuses in the ventricles of the brain, may become more turgid during sleep, and, by a sort of erection, may act as diverticula for the blood in the cranium, whilst the cerebral vessels are proportionally emptied. The less full state of the vessels of the brain-substance has been called its nutritive circulation, and the more full condition, its functional circulation; the vessels of both the choroid plexuses and the brain, may be understood to be governed by the state of the vasi-motor nerves.

Reflex movements still occur during sleep, for the excitability of the afferent and motor nerves, and of those parts of the nervous centres which are not necessary for conscious sensation, but which govern the reflex movements, still remains. The periods of remission and rest of vegetative life, therefore, do not coincide with those of animal life; moreover, they present very great variations in different organs. Thus the heart's substance and its nervous ganglia, must take their rest in the intervals between its pulsations; the respiratory muscles and nervous centres, between the inspirations; and the secreting glands, during the abeyance of their function.

The *causes* of sleep are mental and bodily fatigue, long-continued exertion of the senses, diminution or absence of external impressions, as silence and darkness, monotonous continuance of sensory impressions, as, for example, the humming of bees, also heavy meals, spirituous drinks, certain narcotic agents, and cold. The recumbent posture also induces sleep, not only through habit, but also by increasing the tendency of the blood to the cranium, thus probably causing temporary fulness of the vessels of the choroid plexus, and so diminishing the quantity of blood in the gray matter of the cerebrum.

As regards the internal physiological conditions of sleep, but little is known.

The act of *awaking*, or the cessation of the temporary suspension of the cerebral functions, is either spontaneous, when the nervous parts have recovered from their fatigue, or else it is caused by internal or external stimuli; and this latter is one of the principal points of distinction between sleep and coma, or that absolute state of insensibility from which a person cannot be aroused. Amongst the internal stimuli which interrupt sleep, may be mentioned, very vivid dreams, pain, or sudden disturbances in muscles connected with organic life, as, for example, those of respiration, or the uneasy sensations produced by distension of the intestines or bladder. The external stimuli which interrupt sleep, are strong sensory impressions, such as sound, light, or mechanical disturbance, as, *e. g.*, shock or shaking; the cessation of habitual impressions, on the other hand, may also put an end to sleep—the miller awakening when his mill stops.

Violent sensory impressions, mental excitement, and certain substances, such as tea and coffee, retard sleep, but after severe and prolonged watching, it eventually comes on with greater intensity; cases, indeed, are related of fatigued soldiers sleeping on the march, or even during a cannonade in battle, and of persons slumbering during the infliction of torture. Cases have occurred in which, after sleep has been postponed for several days, it supervened so profoundly, as to pass into coma and death; the celebrated French anatomist and surgeon, Portal, died in this way.

Sleep is necessary for the maintenance of the functions of animal life, and is common to all animals which possess a nervous system. The suspension of the nutritive functions in the lowest animals, which are destitute of nervous substance, if any such exist, and that noticed, during the night, in the leaves and other parts of plants, is not true sleep.

Various circumstances modify the *amount* of sleep required by different persons. Thus, *age* is of great importance; for adults spend, on an average, about one-third of their life in sleep, *i. e.* about eight hours in the twenty-four; infants pass almost the whole, and children more than half their existence in a state of sleep; whereas by old people, less is required; but in extreme old age, life, as in infants, may be said to be almost a continuous sleep. *Temperament* also influences the amount of sleep; thus persons of a plethoric or lymphatic temperament, require more sleep than individuals of a nervous temperament. *Habit*, again, modifies considerably the amount of sleep required by the individual. Pichegru, it is said, only slept four hours out of the twenty-four, during one year's campaign. John Hunter and Frederick the Great required only five hours daily. Lastly, the amount of previous fatigue, whether mental or bodily, of course influences the amount of sleep required. The *invasion* of sleep is, in some individuals, sudden; but it is generally gradual. It is marked by heaviness of the eyes, yawning, and an endeavor to obtain an easy position; luminous spots, bright bodies, and indefinite images, are sometimes perceived, showing the gradual decline of the powers of attention. The imagination is, to a certain extent, active when the senses and the reasoning faculties sleep. The functions of sight are first suspended, then those of taste, smell, hearing, and last of all, that of touch. The muscles of the limbs are the first to become relaxed; whilst those of the back are the last over which voluntary control is lost. Sleep is sometimes protracted for twenty-four hours, or more, in succession. The act of *awaking* is sometimes sudden, but an intermediate state generally exists between sleep and waking. Sleep may be heavy or light, the one state gradually passing into the other; this varies in different individuals. It is most profound and most refreshing during the first hours of rest, many persons being then even insensible to the most powerful external impressions. When sleep is of a light character, very slight stimuli suffice to rouse the individual; in such a condition, many ordinary occurrences are perceived, and not unfrequently, the resulting ideas interweave themselves in the formation of dreams.

During sleep, indeed, although the mind is insensible to external impressions, yet the mental faculties may be in a state of internal activity, simple ideas being formed, or even general notions conceived. This state constitutes *dreaming*. The current of thought, in this condition, is totally independent of the will. Ideas commonly follow each other, in a more or less incongruous manner, sometimes, however, in a uniform and regular order. The character of dreams is influenced by the mental condition in the waking state; hence, when the mind has been busily occupied during the day with certain ideas, these frequently form the subject of dreams at night; so also, when laboring under depressing emotions, dreams during sleep are of a mournful and agitating character. The reasoning faculties are sometimes correctly exercised; cases are on record, of mathematicians solving the most difficult problems in their dreams.

One of the most remarkable and characteristic phenomena of dreaming, is the rapidity with which ideas pass through the mind, events of a lifetime sometimes appearing to occupy but a few seconds. There is frequently total inability to perform certain movements, however great the wish to do so may be; the inability to strike a desired blow, or to escape from, or avoid an imaginary danger in a dream, notwithstanding all our efforts, affords a familiar example of this fact. This, as well as the simple sensation of weight upon the chest, is a form of *incubus* or *nightmare*. It is unknown whether dreaming may be prolonged during the whole period of sleep, or whether it is confined to short intervals between sleeping and waking. The former view is somewhat supported by the occurrence of repeated movements and ejaculations, occasionally observed even in heavy sleepers, and of which they lose all recollection on awaking. But the prevailing opinion is, that dreams are only possible in light imperfect sleep, and that they are incompatible with the condition of the mind in profound sleep. Those dreams which occur during the short interval between sleep and waking, are certainly the best remembered. In light sleep, at the beginning of sleep, when the activity of individual parts of the cerebrum has not yielded to the general state of repose, or, at the end of sleep, when those parts have already regained some degree of consciousness, certain mental faculties come into operation, and by a process of combination, form an ideal and imaginary world. The whole picture is so unreal, and the dreamer is so conscious of it, that often, even during sleep, he knows that he is dreaming; so conscious, indeed, is he of this, that he can either prolong the dream, or at once put an end to it. This condition is, therefore, hardly one of real dreaming, but approaches more nearly to the waking state. Such dreams remain impressed on the memory, with more or less distinctness.

Though, in certain dreams, external impressions may be correctly perceived and combined, it often happens that they are misapprehended, wrongly interpreted, or even ludicrously associated. Thus the effects of cold air, or of evaporation on the skin, may be construed into the touch of an imaginary person or ghost. Many other delusions may be thus explained.

Lastly, internal conditions of discomfort may produce perfect or imperfect impressions, and so give rise to dreams; and may, like external impressions, be rightly or wrongly interpreted in the dreaming state.

That kind of dreaming, in which the individual performs actions, and even speaks, as if awake, without the co-operation of the will, is known as *somnambulism*. In this state, the movements and conversation are determined by the ideas of the dream; but attention to other ideas or impressions, and memory, are entirely suspended; whilst the reasoning is limited, and the control of the pure will over the mental processes is also abrogated. The mind is absorbed in one current of ideas alone. The regular marching of soldiers in sleep, when much fatigued, and the answering of questions, by persons in a state of slumber, are examples of the lighter forms of somnambulism. In the more marked forms, chiefly occurring in hypochondriacal or hysterical individuals, the dreamer performs the most dangerous acts, follows the most perilous paths, and the most unfrequented ways, which he would be unable to do if awake, totally unconscious of any danger. He can see and hear, can dress and undress, opens doors and boxes, and, on awaking, has no recollection of what has happened. In this peculiar state, the body may be altogether insensible to pain, the ear to sound, and the eye to light, however powerful the action of these stimuli. Impressions are not perceived by the senses, so long as the attention of the individual is directed to some other subject or object; but the sensibility of any one sense is much heightened, when the mind is occupied exclusively with ideas solely connected with that sense. Sounds, which in the waking state would hardly be noticed, now appear to produce powerful impressions. In the same manner, the sensibility of the skin, when the attention is directed to it, is greatly exalted; and so on with the other senses. Cases are even recorded, of individuals performing every action suggested; such as fighting, swimming, or hunting; some will imitate drunken men; others will work out the most difficult problems, or go through a train of reasoning; speeches have been made, verses composed and committed to writing; in fact, the attention of a somnambulist can often be directed, at the will of an observer, to any given object or subject. Although, on awaking, he has no remembrance of what has taken place, yet, on relapsing into a similar state, the ideas previously expressed, and the acts performed, may be resumed and continued. Persons who exhibit this extreme degree of somnambulism, have been said to have a *double consciousness*, one memory when awake, another when dreaming. (Wigan.) In some individuals, this state may be artificially induced; but it is generally a natural phenomenon.

The so-called *magnetic* sleep or *hypnotism*, which sometimes occurs spontaneously in nervous persons, but which is more frequently induced by the operations of so-named *animal magnetism* or *mesmerism* is a similar mysterious phenomenon; and the constitution which predisposes to it, seems to depend on analogous abnormal states, It is chiefly observed in nervous, highly excitable, hysterical females. Its occurrence has been placed beyond a doubt, by the evidence of many observers. Indeed, new mental faculties have appeared to some to have been developed, or to have been aroused from a dormant state, by means of mesmerism. Many remarkable movements and actions may, in such persons, undoubtedly be excited by suggestion; powerful contractions of the limbs may be induced, and even certain movements, impressed by others upon the magnetized individual, may suggest corresponding ideas in his mind, lead to the performance of further movements, and so appear to place the individual under the control of the operator.

The manifestations of the so-called *clairvoyants* and *spirit-rappers*, probably rest upon erroneous explanations of facts. Under impressions repeatedly acting on the mind, unusual so-called subjective phenomena may be induced in highly excitable persons, through the medium of the nervous centres. In the delirium of fever or of insanity, the thoughts, expressions, and acts of the patient, are often directed by an occasional question or remark made by a bystander; hence credulous persons may perceive, in the expressions of such individuals, supernatural manifestations; and similar phenomena are induced by so-called animal magnetism. It usually happens that, in questions of this intricate nature, those are the most dogmatic who, by their previous habits of thought and education, are the least qualified for such investigations. No right of opinion upon such difficult questions can be granted to enthusiastic dilletanti, or to the worshippers of a longing desire for notoriety.

THE NERVOUS SYSTEM AND ITS FUNCTIONS IN ANIMALS.

The nervous system in animals has already been described (pp. 106 to 112). In the Vertebrata, it is constructed on a plan similar to that of Man, consisting of a *cerebro-spinal* system, composed of brain, and spinal cord, with cranial and spinal nerves; and of a *sympathetic* system, composed of a double ganglionated cord, with branches of distribution. In the Mollusca, the nervous system is composed of ganglia scattered through the body, and of nervous cords connecting them, or passing from them, to be distributed to the various parts of the body. In the Molluscoida, there is but a single central ganglion, with branches of distribution. In the Annulosa, there exists a series of ganglia with intervening cords, arranged like a chain on the under surface of the body, and having numerous branches proceeding to the various segments and their appendages. In the Annuloida, as in the Molluscoida, either the ganglionic centre is single, or numerous connected ganglia correspond with the radiated form of the body. In the Cœlenterata, the nervous system, when seen, consists also of a central ganglionic mass, with nerve trunks proceeding from it. In the Protozoa, no nervous system has been discovered.

However varied in its anatomical disposition, in different animals, the nervous system consists essentially, of a central mass or masses of gray matter, connected, in various ways, with nerve fibres; many of these, as in the cerebrospinal axis of the Vertebrata, and in the multi-ganglionated system of the Mollusca and Annulosa, are connecting or commissural between different gray masses; whilst others form the branches, called nerves, proceeding from the gray matter. Physiologically considered, there can be no doubt, as indeed experiment sufficiently demonstrates in certain cases, that, in animals as in man, even in the simplest forms, in which the nervous system consists of but a single ganglionic centre, the nerve-fibres act internuncially, as mere conductors of the effects of impressions produced upon them; whilst the gray matter, whether aggregated in certain parts of a cerebro-spinal axis, or collected in a small ganglionic mass, is not only a conductor of the effects of impressions, but may transfer, radiate, or reflect those impressions, and may constitute a central sensorium, for the reception of sensory impressions, and, in the higher animals, a centre of origin of motorial stimulus. The gray matter always manifests higher endowments than the nerve-fibres, whether white or ganglionic. As we have seen, in the study of the human nervous system, some of these fibres must be afferent and some efferent; certain afferent fibres are concerned in the conduction of sensory impressions only, as, for example, the nerves of sight; whilst others conduct the effects of stimuli to the gray matter, from which a motor influence is reflected upon certain efferent fibres, in reflex actions, either sensori-motor, or simply excito-motor; whilst lastly, other efferent fibres conduct motorial impressions, which have, according to the position of a given animal in the scale, a more or less distinct ideational, emotional, or volitional character. As in man, too, the effects of the volitional stimulus, are of course directed upon the muscles concerned in locomotion; whilst the involuntary, or reflex, movements partly occur in the locomotive muscular system, and partly, as in man, in the muscular structures concerned in the functions of vegetative life.

The amount of nervous force manifested by any animal, whether in the phenomena of sensation, or of the regulation of its voluntary and involuntary movements, is strictly in accordance with the relative mass, and complexity of organization, of its nervous centre or centres. It is certain, therefore, that sensation and the power of regulated motion, as well as the higher psychical endowments, by which the animal is governed through trains of ideas, emotions, memory, reasoning processes, and will, are more highly developed in the Vertebrata, than in the lower subkingdoms, in which, at length, all sensation and regulation of movement must be reduced to a minimum, and so finally become extinct. As we descend in the scale, the higher psychical endowments first fade away; the ideational, emotional, reasoning, and volitional faculties disappear, probably not being manifested by any creatures below the Vertebrate type; and, even in the highest of these, the controlling power of the will over the direction of the thoughts, so peculiarly marked in man, is of doubtful existence. Sensori-motor power, or pure instinct, still persists as the special *automatic* paramount guiding force, as in insects, for example. In yet lower forms, the movements are probably not even instinctive, but excito-motor or purely reflex; and lastly, in the very lowest forms, the movements are probably performed by the immediate stimulation of an insensible contractile tissue, altogether independent of nervous influence, as in the case of the ciliary motion of the Infusoria, or of the irregular movements of the Amœba. Even in the highest animals, the ciliary motion, as already stated, appears to be independent of the action of the nervous system.

Whilst, however, in the preceding general sketch, it is assumed that the nervous system dies out, or disappears, before we reach the lowest confines of animal existence, because no nervous system has been there detected, yet it has been maintained by some, that nervous substance may possibly exist in microscopic ganglia which escape detection; or that it may be diffused, in the shape of single nerve cells, in the bodies of the minuter organisms; or lastly, that it may even form a portion of the contents of a uni-cellular animal, that is, of an animal organism consisting but of a single nucleated cell. If these conjectures be true, we must conclude, that no animal exhibits movements, resulting from the direct stimulation of its contractile substances by external agents; but that, even in the very simplest forms, nerve substance may regulate those movements.

The nervous system is an apparatus working so completely in accordance with its structural peculiarities that the successive stages by which its functions are gradually simplified may be best followed, and its adaptations to the actions and wants of animals of lower and lower organization be most readily understood, by tracing the numerous gradations, both general and particular, which it presents in different animals.

Vertebrata.

The *Encephalon* or entire brain.—The only animals in which the entire encephalon is absolutely heavier than in man are the very largest cetaceans and pachyderms; thus, in the whalebone whale its weight is about 5 lbs., and in the elephant it varies from 8 to 10 lbs., being heavier than in any other known animal.

The weight of the encephalon as compared with that of the body diminishes in the Vertebrata generally in the following order and manner. In Mammalia it is as 1 to 186; in Birds as 1 to 212; in Reptiles as 1 to 1321; and in Fishes as 1 to 5668. (Leuret.) Amongst the Mammalia the encephalon as compared with the body is proportionally smaller in the larger species than in those of less dimensions; thus in the ox it is as 1 to 860; in the elephant as 1 to 500; in the horse as 1 to 400; in the sheep as 1 to 350; in the dog as 1 to 305; in the cat as 1 to 156; and in the rabbit as 1 to 140; in the rat as 1 to 76; and in the field mouse as 1 to 31. In all these cases, with the exception of the last, the brain is heavier, relatively to the body, than it is in man, in whom the average proportion is as 1 to 36.5. In a few other animals the entire brain is also heavier, relatively to the body, than it is in man; as in the marmozet monkey, in which the proportion is as 1 to 22, and in certain small singing birds, as the linnet, goldfinch, and canary, in which the proportions vary from 1 to 24 to 1 to 14, whilst in the blue-headed tit, the ratio is even as high as 1 to 12. From these facts it appears that, in comparison with the size of the body, Man has a far larger brain than the Vertebrata, even than the warm-blooded groups; but there are exceptions in the case of a few small birds, in certain small rodent animals, and in the smallest of the monkey tribe. According to recent observations, however, the entire brain of man is heavier, in comparison with the body, than it is in the anthropoid apes, the proportion in an adult Chimpanzee being about 1 to 50. These facts, especially those derived from a wide comparison of the weight of the brain and body, in the different classes of the Vertebrata, show such a correspondence between the relative size of the brain and the amount of intelligence exhibited by those animals, as to justify the general inference that the brain is that part of the organism through which the manifestations of intelligence take place; for, with apparent exceptions, too few to influence the general conclusion, these facts demonstrate the large relative preponderance of the brain in man associated with his higher mental endowments. In reference to the numerical estimates above given of the ratio between the size of the brain and the weight of the body, it must, however, be remarked that the sensory and motor ganglionic masses at the base of the cerebrum, viz., the optic thalami and corpora striata, are always included in the weights; and moreover that these parts in the lower Mammalia, and especially the corpora striata in Birds, constitute by far the larger part of the so-called cerebral lobes. Hence the numbers do not show the relative size of the parts supposed to be concerned in the manifestation of intelligence, viz., the cerebral hemispheres, properly so-called. Correct estimates would necessitate the removal and weighing of the parts which really form the hemispheres in the lower Vertebrata. But besides size, other conditions have to be considered, particularly the extent of surface and complexity of structure, the quantity of gray matter, and the number of commissural fibres.

The same general physiological deduction is justified by a comparison made by Sœmmerring between the transverse diameter of the brain and that of the medulla oblongata, regarded as representing the great *root* of the various nerves of the body. Thus, in man the width of the cerebrum as compared with the medulla oblongata is as 7 to 1; in the orang-outang 6 to 1; in monkeys generally 5 and 4 to 1; in the cat 2.75 to 1; in the rabbit 2.66 to 1; in the horse 2.625 to 1; and in the ox 2.6 to 1. Again, the weight of the entire brain as compared with that of the spinal cord, which in man is about 40 to 1, is, in the mouse, 4 to 1; in the pigeon, 3.5 to 1; in the newt, .55 to 1; and in the lamprey, .013 to 1; showing a progressive diminution in the brain as compared with the cord, in the mammal, bird, amphibian, and fish. In the last two cases it will be noticed that the brain weighs even less than the cord; and it is in such animals that we find the movements become more and more sensori-motor or instinctive, or even purely excito-motor or reflex movements, which, as we have already seen, are governed by the spinal cord, the medulla oblongata, and their extensions upwards to the base of the cerebrum, rather than by the cerebrum properly so called.

Not only does the *size* of the entire encephalon become relatively less as we pass from the highest to the lowest Vertebrata, but this part of the nervous system undergoes a gradual simplification in its *form* and *structure*, more especially as regards the parts which, in this series of animals, represent the *cerebral hemispheres* and the *cerebellum.* These organs indeed, so decline in size and complexity that they become gradually smaller in proportion to the sensori-motor ganglia at the base of the cerebrum; or in other words, as we descend in the vertebrate scale these ganglia exhibit a greater proportionate size as compared with the diminished cerebral hemispheres and cerebellum. With the diminution of the cerebellum, there appear to be associated a diminished complexity and variety of the muscular movements executed by the lower Vertebrata; whilst the remarkable defect in the cerebral hemispheres is accompanied by defective intelligence.

The *Cerebral Hemispheres.*—In the most intelligent mammiferous animals, the anthropoid apes, these parts completely cover the olfactory nerves or lobes in front, and the corpora quadrigemina behind, being indeed, as in man, prolonged so far backwards that they completely cover, and even overlap the cerebellum. In many species of the still lower baboons and monkeys (Fig. 63, *g*), the amount of overlapping is even greater than in man. But in descending through Carnivora, *e*, Cheiroptera, Ruminantia, and Pachydermata, and the still lower Rodentia, the cerebral hemispheres no longer overlap, but soon cease even to cover any part of the cerebellum, which ultimately is completely visible when the encephalon is viewed from above. In the Ruminantia, *f*, the anterior part of the hemispheres is also so proportionally diminished as to permit the large olfactory lobes to project beyond them; whilst in the Rodentia

Fig. 63.

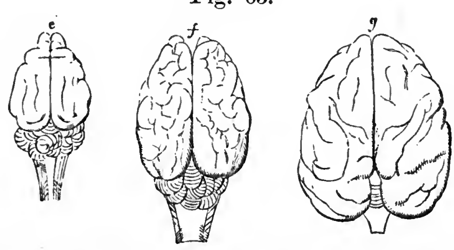


Fig. 63. Brains of three of the Mammalia, to show the gradually increasing size and complexity of the cerebral hemispheres, in the ascending scale of those animals. *e*, brain of the cat, showing the cerebrum, and its few simple, almost exactly symmetrical convolutions: behind it is the much-lobulated cerebellum and the medulla oblongata; and in front a portion of the olfactory lobes. *f*, brain of the sheep; the olfactory lobes are almost hidden, and the cerebellum is about half covered by the cerebral hemispheres, which are now more complex and less symmetrical. *g*, brain of a monkey, in which the olfactory lobes in front, and the cerebellum behind, are completely overlapped by the cerebrum; the convolutions are now constructed on the plan observable even in the human cerebrum: a distinct posterior lobe can be recognized, but the cerebrum is more pointed in front, its convolutions are more simple and symmetrical, and its relative size very much smaller than in man.

(Fig. 64, *d*), owing to the still further diminution in the hemispheres, even a portion of the corpora quadrigemina behind, becomes visible. In Birds, *c*, the cerebral hemispheres overlap the small olfactory lobes in front; but behind, a very large portion of the optic lobes is visible. In the Reptiles and Amphibia, *b*, a still further reduction of the cerebral hemispheres takes place. Lastly, in the Fishes, *a*, they are relatively so small as merely to invest the corpora striata with a thin layer of cerebral substance; in these lowest Vertebrata, the parts of the encephalon are, so to speak, analyzed, being arranged in a series of three pairs of ganglionic masses, placed in a double symmetrical row, one behind

Fig. 64.

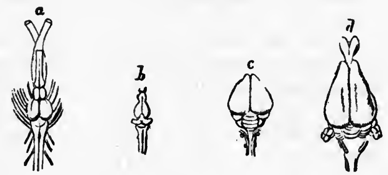


Fig. 64. Views of the upper surface of the brains of a fish, amphibian, bird, and mammal, showing the gradual increase in the size of the cerebral hemispheres. *a*, brain of the codfish, showing, from behind forwards, part of the spinal cord, the back of the medulla oblongata, the median cerebellum, the two large optic lobes, the small cerebral hemispheres, consisting chiefly of the corpora striata, the narrow olfactory lobes and olfactory nerves, and lastly, the decussating optic nerves. *b*, brain of the frog, in which the cerebral hemispheres are the largest masses; the olfactory lobes are seen in front, and the optic lobes, projecting laterally behind; the cerebellum is a thin transverse lamina. *c*. brain of the pigeon; the largest masses are the cerebral hemispheres. In front are seen the ends of the olfactory lobes; behind, the cerebrum, and projecting at the sides, are the optic lobes and corpora quadrigemina; and, in the middle line, the laminated central lobe of the cerebellum, with its small lateral appendages. *d*, brain of the rabbit, showing in front, the large olfactory lobes; next behind them, the cerebral hemispheres, pointed in front, slightly sulcated, and now, by far the largest mass of the encephalon: behind them, the cerebellum and its floccular appendages; and lastly, the back of the medulla oblongata.

the other, and of a single median mass behind them. The anterior pair of these ganglionic masses, form the *olfactory lobes;* the second pair, named the *cerebral lobes*, are composed of the corpora striata, covered with a thin layer of cerebral substance, which forms the rudimentary cerebral hemispheres; the third pair, usually the largest, correspond with the optic thalami and corpora quadrigemina, and, as they give origin to the optic nerves, they are called the *optic lobes*. Behind them is the small median mass representing the *cerebellum*.

In Fishes, therefore, the thin cerebral hemispheres must fulfil a very subordinate office in the nervous functions; in Amphibia, Reptiles, and even in Birds, they are still small, and their component gray matter is of but little thickness; but so largely developed as they are in the Mammalia generally, especially in the highest forms, and, above all, in Man, they appear, as already mentioned, more like superadded parts, overlapping all the other encephalic masses.

The progressive complexity of *surface*, of the cerebral hemispheres, is indicated by their smoothness in Fishes, Amphibia, and Reptiles; and by their faintly marked sulcation in certain birds. In the lowest Mammalia, and even in the smallest and lowest genera of the highest order of Mammals, the hemispheres are also smooth, or nearly so, as, for example, in the Monotremata and Marsupialia, in the lowest Rodentia, and even in certain lemurs, the lowest of the so-called Quadrumana. As we advance in the ascending series of Mammalia, or in the ascending series of genera in certain Orders, the hemispheres become more and more sulcated on the surface, and finally, are modelled into the curved or tortuous ridges called convolutions, which, speaking generally, become more and more numerous and complex, as we reach the highest Mammalia, or the highest genera in the several Orders.

These *cerebral convolutions*, which may be said to be peculiar to the brains of Mammalia, may be considered—first, in reference to their general *plan* in any given group or groups; and secondly, as regards their relative *complexity* within that plan. In the Pachydermatous and Ruminant animals, for example, the convolutions are chiefly arranged in the form of parallel folds, extending from the front to the back of each hemisphere; and, for the most part, present a more or less flexuous outline. In the Carnivora, on the other hand, the surface of the hemispheres, is divided into four principal antero-posterior convolutions, which seem to bend, in simple curves, around the upper end of the Sylvian fissure, one above the other, and pass continuously from the anterior or frontal, into the middle or parieto-temporal lobe. In neither of these Orders, nor in those lower in the scale, as the Rodents, Marsupials, and Monotremes, is there a distinct portion of the hemispheres, marked off from the other lobes, to form a posterior or occipital lobe; indeed, in these latter groups, even the middle lobe seems to be rudimentary. In the Ruminants and Pachyderms, traces of a fissure of Rolando may be detected; but in none of the preceding groups, not even in the Carnivora, excepting in the seal, is there to be found, within the cerebrum, a prolongation backwards of the lateral ventricle, in the form of a posterior cornu; in the seal, a rudimentary cornu, with its contents, first appears. It is not to be inferred from this, however, that there does not exist some small portion of the cerebral hemispheres of these animals, which is anatomically and physiologically homologous with, or representative of, the parts called the posterior lobes in the still higher Mammalia, and in Man; but all we are entitled to say is, that the plan of structure of the hemispheres, excludes such subdivisions or markings, as serve to distinguish a part, as a posterior or occipital lobe. In all the so-called Quadrumana, however, which amongst the Mammalia are nearest to man, and which, as we have seen (p. 107) have been zoologically associated with him, in a common Order, named Primates, another plan prevails, in the arrangement of the substance of the cerebral hemispheres, which indeed corresponds fundamentally, with the plan observed in the human cerebrum. It is one part of this plan, that the existence of a posterior or occipital lobe, should be indicated internally, by the extension backwards, into that part of the hemisphere, of an included prolongation of the lateral ventricle, forming a distinct posterior cornu; besides this, when traces of fissures appear upon the surface of the hemispheres, they occupy the position of the principal fissures of the human brain, viz., the fissure of Rolando, marking off the frontal from the parietal lobe; the internal perpendicular fissure, distinguishing, even on the surface, the occipital, or posterior, from the parietal, or middle, lobe; and the fissure of the hippocampi, formed by the folding inwards of the cerebral substance, along the floor of the posterior cornu. In the higher monkeys, the baboons, and the anthropoid apes, other sulci appear between the principal fissures, serving, step by step, to complicate the cerebral surface, and to mark it off, into more and more numerous convolutions, the general arrangement of which is undoubtedly correspondent with that traceable in the far more complex array of convolutions in the human brain. In all these, there may be recognized certain primary frontal, parietal, occipital, and temporal convolutions, which have, as in the Ruminant and Carnivorous brains, a general longitudinal direction; and, in the higher forms, secondary convolutions are interposed. Both the primary and secondary convolutions become progressively more tortuous; and certain of the latter are met with only in man. It is beyond doubt, however, that the cerebrum of the so-called Quadrumana, and that of Man, are constructed on a common plan; but when we consider its absolute size, or, more especially, its relative size, as compared with the cerebellum, the spinal cord, or the entire body, the relative development in particular of its frontal and parietal regions, furthermore, the number and complexity of its secondary convolutions, and lastly, the thickness of its gray matter, and the amount of its commissural fibres, there exists an enormous difference between the cerebrum of man and that of the highest anthropoid ape. There is not, indeed, in these respects, so great a difference between them, as exists between the lowest and the highest of the so-called Quadrumana; but there is a vastly greater difference than is found between the brains of any two quadrumanous species, or even between the brains of the *different genera*. Recent researches on this subject, whilst they have served to show a closer affinity, than was before believed to exist, between the Quadrumana and Man, still leave a wide and unbridged chasm between them; nor do geological researches yet offer any intermediate and progressively approximating cranial forms.

Of the several plans of the cerebral convolutions of the Mammalia, thus briefly sketched out, it is difficult, at present, to say that the Pachydermatous and Ruminant plan is necessarily inferior to the Carnivorous plan; but there can be no doubt, that this latter is decidedly lower than the plan observed in the Primates, which include the so-called Quadrumana and Man.

In regard to the relative *complexity* of different brains within each plan, a very general rule has been observed (though exceptions to it have been pointed out), viz., that the cerebral hemispheres are more convoluted in the larger species or genera of any great group of the Mammalia, than in the smaller species or genera of such groups. For example, this is true successively of the larger as compared with the smaller Quadrumana, as seen in the orang, the baboons, the monkeys, and the lemurs; of the larger and smaller Carnivora, as in the seal and the cat; of the larger and smaller Pachydermata, as in the elephant, horse, and pig; of the larger and smaller Ruminants, as in the ox and sheep, and so on. The case of the elephant is perhaps the best single known illustration of the striking relation between the size of the body and the complexity of the cerebral convolutions, which are singularly numerous and tortuous in that large animal. They are also very complex in the somewhat allied, and usually bulky, Cetacea. As an exception to the general rule, it is stated that the brain of the horse is less complicated than that of the ass, although the former animal is larger; but the pony's brain is certainly more complex than the donkey's. Again, the brains of the lion and cat, notwithstanding the difference in size between their bodies and their brains, also present none in the degree of complexity of their cerebral convolutions. It has been suggested, that the relatively more convoluted cerebrum of the larger species, is to enable the necessary amount of gray matter to be contained in a cranium of a given size, otherwise, the head would have been inconveniently bulky (Dareste); but this is probably not the whole explanation, or there would be no exceptions. Besides this, the cranial cavities of the elephant and whale are not nearly so large as their heads would allow. However, it has been shown, that, although the effect of the convolution of the surface of the cerebrum, is to increase largely the quantity of gray matter, yet the size or weight of this organ by no means increases, *pari passu*, with the complication of its surface; for, in proportion to its surface, which is so highly convoluted, the cerebrum of man is only two-and-a-half times as large as that of the rabbit, the surface of which is quite smooth (Baillarger); the larger quantity of medullary commissural fibres in the superior brain, accounts for this.

In brains still more simple than those of the lowest Mammalia, not only are there no convolutions, but neither external nor internal distinctions into lobes. A few symmetrical lines only are traceable in Birds, but none whatever in Reptiles, Amphibia, and Fishes. The so-called cerebral lobes, or rather their superficial layers, in these four oviparous classes of Vertebrata, are by some, indeed, supposed to represent the anterior lobes only, of the hemispheres of the cerebrum in the Mammalia; first, from the absence of the corpus callosum, and secondly, from their connection with other parts. The middle lobes are believed to appear first, in the lower Mammalia, and afterwards, the posterior lobes in the higher forms. But, as already intimated, the lobes may not be distinguishable, and yet homologous parts of the cerebral hemispheres may be present, however slightly developed, throughout all the Vertebrata.

Amidst the known varieties of plan, and all the degrees of complication of the cerebral convolutions within the limits of each plan, one particular feature seems to be of considerable importance in estimating the relative superiority of any given brain. We allude to the degree of symmetry of the convolutions of the two hemispheres. In the simple, diminutive hemispheres of the Fish and Reptile, even in the more highly developed, and slightly sulcated, hemispheres of certain Birds, and in the smooth cerebra of the Monotremata and Marsupialia, and of the lower Rodentia, and the lemurs, the symmetry of form is apparently exact. As soon as any markings appear on the hemispheres, and even when these are tolerably numerous, as in the Carnivora and more highly developed monkeys, they are very symmetrical on the two sides; but in the more complex brains of the larger Pachydermata and Ruminantia, especially in the horse and elephant, and also in the still more highly developed brains of the anthropoid apes, a certain want of symmetry becomes apparent. But it is in the human brain more particularly, that exactitude of symmetry disappears. In fact, the extraordinary relative size of the cerebral hemispheres, the number of its secondary convolutions, and the absence of symmetry in the forms and dispositions of all the convolutions, constitute the three great external distinguishing characters of the human brain.

If, finally, we regard the general plans, and the secondary arrangements, of the cerebral hemispheres in the different Vertebrata, from a physiological point of view, we find a close general correspondence between the amount of intelligence manifested by the several members of this series, and the degree of complexity of the cerebral hemispheres. It has even been noticed that, in different varieties of one kind of animal, subjected to different conditions, as regards education, and therefore exhibiting various grades of active intelligence, the general development and size of the cerebrum, keep pace with the growth of that intelligence; for the brains of trained and domesticated dogs, are proportionally larger than those of the wild dog. But hitherto, the attempts made by psychologists and comparative anatomists, to associate, with certainty, particular parts of these hemispheres, with particular psychical endowments, have proved abortive.

The ganglionic masses at the base of the cerebrum.—The *corpora quadrigemina* are still divided, as their name implies, into four eminences throughout all the Mammalia; the anterior pair are larger in the Herbivora, and the posterior pair in the Carnivora. In Birds, Reptiles, and Fishes, these bodies are *bigeminal*, consisting of only a single pair of tubercles, or ganglionic masses, which are closely attached to the optic thalami, and form the so-called *optic lobes;* in the osseous fishes, these optic lobes include the optic thalami, or supposed centre of common sensation. The *corpora striata* are always, throughout the whole of the Vertebrata, as in man, concealed by the cerebral hemispheres; but as these latter parts are more and more reduced in size, the striated bodies become more and more apparent, and at last, in the Fishes, constitute almost alone, the so-called *cerebral lobes*, a very thin layer of gray matter, forming the only remnant, or representative, of the cerebral hemispheres. In Birds, and in the higher cartilaginous fishes, a ventricular cavity, into which the striated bodies project, is found in these cerebral lobes. It has been suggested, that not only consciousness of simple sensations, but their perception, or the reference of these to their proper external objects, is accomplished in the sensorial ganglia at the base of the cerebrum, at least in these lower Vertebrata (Carpenter); but this view is hypothetical. The size of the optic, and also that of the olfactory lobes, varies in different groups of animals; thus the *olfactory lobes* are larger in animals which possess an acute sense of smell, as in certain Carnivora, in the Ruminantia and Rodentia, and even in the shark tribe amongst Fishes; whilst the *optic lobes* are very large in Birds, animals in which the sight is very powerful, and also in certain Fishes.

Structure of the Cerebrum.—The internal structure of the cerebral hemispheres, also undergoes simplification in the descending vertebrate series. As we have seen, the *lateral ventricles* become smaller in extent, and of simpler form, their posterior cornua being absent, except in the seal, in animals lower than the Quadrumana. The thickness of the *gray matter* of the hemispheres also gradually diminishes, in passing from the higher to the lower Vertebrata. The layer of cortical substance in Fishes is so thin, that these parts of the encephalon appear almost white to the naked eye. It is obvious, that the numerous layers distinguishable in the cortical substance in man, and which have also been seen in the Mammalia, must gradually become fewer, and at last disappear. The quantity of *medullary substance*, although proportionately to the gray matter greater, is also absolutely diminished, and the arrangement of its fibres becomes much simplified. This appears especially to be the case as regards the fibres which, in the higher brains, pass from one set of convolutions to another set, or, in the smooth brain, from one part of a hemisphere to the other. So, too, a very significant diminution takes place in the number of the transverse commissural fibres which serve to unite the right and left halves of the cerebrum, and to bring their respective bilateral parts into physiological connection. The *corpus callosum*, for example, which, in the brain of man, and in that of the higher Mammalia, is of such great extent and thickness, and contains the chief part of these transverse commissural fibres, has been shown to be relatively smaller, even in the highest anthropoid apes, than it is in man. Speaking generally, when examined in a median section, it becomes shorter from before backwards, and thinner, and, gradually losing its horizontal position, is inclined upwards and backwards in the lower Mammalia; in the Rodents it becomes very short and thin, and nearly vertical. In the Marsupialia, it is so rudimentary, and so limited to the anterior part of the fissure between the hemispheres, as to have been described as absent, there being no transverse bridge of cerebral matter, connecting the two hemispheres above the ventricular cavities; there exists, however, a compact transverse commissural mass, situated at the anterior part of the base of the brain, and besides this, the so-called anterior commissure is largely developed. In no Vertebrate animal lower than the Mammalia, is there any trace of a corpus callosum, but there are merely transverse commissural fibres, crossing at the base of the cerebrum, as is seen in Birds, Reptiles, Amphibia, and Fishes. In the Mammalia, its size, and its development backwards, are exactly proportional to the size, and extension backwards, of the cerebral hemispheres, until they even overlap the cerebellum, as in the Quadrumana and in Man.

The gradual simplification, in the number and connections of the white fibres of the cerebrum, must involve a less perfect physiological co-operation, or combination of actions, between its several parts; and it is obviously associated with retrogressively inferior psychical endowments. But the facts of structure, and the observations on the powers and characters of the lower animals, which might throw light on the special physiology of the cerebral hemispheres, remain for future inquirers to collect.

The Cerebellum.—Like the cerebrum, the cerebellum gradually diminishes in size, as compared with the spinal cord, or with the weight of the body, in passing from the highest to the lowest Vertebrata; though, if compared with the cerebrum, it is larger in many of the lower Vertebrata than in man, owing to the extraordinary development of the cerebral hemispheres in him. The principal anatomical feature of the highest forms of the cerebellum, is the great development of its lateral masses, or *hemispheres*, which, however, are still proportionally very large in the Quadrumana. Considered generally, the lateral parts diminish rapidly in the lower Mammalia, until, at last, they are represented only by the small portions named the *flocculi*. In Birds, the hemispheres are represented by still smaller lateral appendages, the great bulk of this organ, in them, being evidently composed of the *central lobe* or *vermiform processes;* whilst in the Reptiles, Amphibia, and Fishes, this median portion is alone present, so that it would seem to be more fundamentally important than the superadded lateral parts or hemispheres.

The structure of the cerebellum, as well as its size, become also progressively simplified. The number of its laminæ diminish, until at last, as in the Birds, they are comparatively few; whilst, in the Reptiles, Amphibia, and Fishes, its surface is commonly quite smooth, but still, however, consists of a thin stratum of gray matter. In the frog, the cerebellum forms a simple smooth curved band; and in the lowest Fishes, it is reduced to a thin layer of nervous substance, too small to conceal the back of the medulla oblongata; but in some cartilaginous Fishes, as in the sharks, for example, the otherwise simple median cerebellum is slightly notched, or laminated, upon its surface. In certain Mammalia, as in the Carnivora and Ruminantia, the cerebellum, instead of consisting of broad and comparatively smooth lateral hemispheres, joined by a narrow median and much-divided portion, or vermiform process, is very uneven upon its surface, apparently consisting of a cluster of many irregular and deeply foliated lobules.

The internal structure of the cerebellum also becomes simplified, in accordance with the gradual diminution in the number of its laminæ; so that the appearance, on a section, named the *arbor vitæ*, ceases to be distinguishable. The *corpora dentata* exist in all Mammalia, but they are less plicated, and, in the lowest forms, present on a section a smooth outline; they have not been seen in the oviparous Vertebrata.

Physiologically considered, the size and complexity of structure of the cerebellum, appear to be in harmony with the degree of complication of the movements capable of being executed by any given animal; for example, it is relatively larger, in the apes and monkeys, than in the Carnivora, and larger in these, than in the Ruminants or Rodents; it is also larger in Birds than in Reptiles; and it is larger in the active predaceous sharks, which can turn themselves round and round, and even swim sideways in the water, than in the ordinary and more simply swimming fishes. Again, in comparing individual genera of the same Order, this organ is more developed in the Anthropoid apes, than in the monkeys, the former being able to assume a more manlike attitude than the latter; and it is also larger in the bear, which can temporarily assume an erect posture, than in the dog. In Man, in whom the cerebellum reaches its highest development, besides the innumerable and complex movements of the upper limbs, the co-ordination of the multitudinous individual motions, necessary to preserve the equilibrium of his erect body, in standing and walking, is much more perfect than that required in the quadruped form of locomotion; and, again, in Birds, in which the cerebellum is still more simple than in Mammalia, the movements of the wings are also more simple, employ but few muscles, are maintained for a long time without fatigue, and exhibit rather an automatic than a volitional character, as shown by the attempted flight of birds when deprived of their cerebrum, or even when decapitated.

The pons Varolii.—In proportion to the gradual diminution of the cerebellum, especially of its lateral parts or hemispheres, the pons Varolii becomes diminished in size; and when the hemispheres are reduced to insignificant appendages, as in Birds, or are absent as in Reptiles, Amphibia, and Fishes, the pons does not exist, a fact which indicates the physiological use of the pons, to be to establish functional relations between the two hemispheres of the cerebellum.

The Medulla Oblongata and Spinal Cord.—The medulla oblongata also shares in that gradual simplification, which is observed in the rest of the encephalon, in the descending series of the Vertebrata. The first parts to become diminished, and then to disappear, are the *olivary bodies*, their *corpora dentata* and the columns of white matter connected with them, these parts not being distinctly present below the Mammalia. The anterior and posterior pyramids, and the restiform bodies, accordingly gradually preponderate, and finally constitute the entire mass of the medulla oblongata, the size of which presents a general correspondence with that of the body of the animal, and becomes larger, in proportion to the cerebrum, in the descending vertebrate scale. The triangular depression formed, on its posterior surface, by the divergence of the restiform bodies, becomes plainer in the lower animals, and is more directly continuous with the central canal in the spinal cord. In certain Fishes, the two halves of the medulla, are actually separate from each other, leaving an oblong opening in the middle line, which has been compared, though incorrectly, with the ring or collar of nervous substance, which surrounds the œsophagus in the Mollusca and Annulosa: for the œsophagus never perforates this divided medulla oblongata, even in the lowest fishes.

The spinal cord likewise exhibits signs of simplification. Its two enlargements, cervical and lumbar, are present in all the Vertebrata which possess well-developed anterior and posterior limbs. In most of the Mammalia, the lumbar enlargement is of greater size than the cervical enlargement. But amongst Birds, those which are remarkable for their powers of flight, like the eagle, have the cervical enlargement larger than the lumbar; whilst, in the cursorial or running birds, as in the ostrich, the reverse is the case. In the limbless Ophidian Reptiles, and also in the Fishes, the pectoral and abdominal fins, or limbs, of which are so small, and have such minute muscles, both these enlargements are entirely absent, and the cord is of uniform diameter, or finely conical, gradually increasing from its lower end upwards. The extent to which it descends within the spinal canal, is greater in the cold-blooded Vertebrata generally, than in Mammalia and Birds. In certain Fishes, in which the body is very short, the cord is equally concentrated, and the cauda equina is very long. In a few rare Cyclostomatous fishes, as Orthagoriscus and Trigla, the cord presents numerous constrictions, which give it a beaded appearance, and prove the real segmented character of the spinal nervous axis, which, in the Vertebrata generally, is masked by the even fusion of its parts.

It would seem, that in certain vertebrate animals, as distinguished from man, more of the longitudinal fibres found in the spinal cord are commissural between its several parts, or else are concerned in connecting the roots of the spinal nerves with its own gray matter, whilst fewer ascend, from the nerves, to the sensorial centres at the base of the cerebrum; this has been shown at least to be the case, in regard to the spinal cord of the horse. (Volkmann, Kölliker.) In accordance with this, the locomotive movements of such animals, are either consensual, or sensori-motor, or, as in those very low in the vertebrate scale, even purely excito-motor, becoming thus gradually less dependent on, or wholly independent of sensation; less associated with ideas of purpose, less influenced by education, and at last, perhaps, purely automatic, and wholly dependent on the internal structure of the nervous apparatus contained in the spinal system. In the higher Mammalia, and in man, however, the locomotive movements are, to a greater extent, guided by sensation, and are commonly regulated by proper cerebral or mental processes. It has further been observed, as the result of section of the cord, that, in Birds and Reptiles, the decussation of the paths of sensation in the cord is less direct, and less perfect, than in Mammalia. In the Amphibia, as in frogs, the movements performed, through the spinal cord, in the decapitated animal, are so purposive, that they simulate the volitional acts of the higher Vertebrata and of man, but their marked uniformity justifies the denial to them of any volitional quality, a view also supported by analogy, which is opposed to the supposition that psychical endowments can be manifested by the spinal cord, in some Vertebrata, and not in others.

The Cranial and Spinal Nerves.—The cranial nerves, in the Vertebrata generally, correspond in arrangement, general distribution, and function, with those which we have described in man; but in certain cases, some of them are absent, whilst others may have a more extensive, or a limited, distribution and office, than they have in man. For example, the olfactory nerves are absent in certain Cetacea; and the optic nerves are wanting in the Mole, and in the blind Fishes found in perfectly dark subterranean caves, as in those of Kentucky. Again, the hypoglossal nerve is more complete in the cat, ox, and rabbit, than in man, for it has a posterior root, with a small ganglion upon it, and so, resembles exactly an ordinary perfect spinal nerve. On the other hand, this nerve becomes very small in certain animals, such as Birds, in which the tongue is but slightly developed; and it is still smaller in Fishes, in which it may be ranked with the spinal nerves. In certain fishes too, the fifth pair of nerves has an unusually extensive distribution, sending, in particular, a large branch, the so-called great *lateral nerve*, down the whole length of each side of the body. In Fishes, also, the vagi or pneumogastric nerves, although they no longer supply lungs, nevertheless send branches to the substituted respiratory organs, the gills.

The Sympathetic Nervous System.—The sympathetic nerve is well developed in all the Vertebrata, and is constructed on the same plan as in man, consisting of a double ganglionated cord, communicating at numerous points with the cranial and spinal nerves, and giving off branches forwards, on which prevertebral ganglia are found, and supplying all the viscera, its ultimate twigs spreading out on the coats of the small arteries. Its offices are doubtless the same as in man; for it presides over the lowest, or vegetative system of functions.

The Nervous System of the Amphioxus or Lancelet.—This little animal, which is the lowest Fish, and therefore stands at the bottom of the whole Vertebrate series, is so remarkable, as here to deserve a special notice. It is found principally in the Mediterranean, on the coast of Italy; but it has been, though rarely, caught in the Atlantic, and even as far north as the British seas. It is an oblong transparent animal, about three-quarters of an inch in length, blunt at its anterior, and pointed at its posterior extremity, slightly flattened at its sides, and provided with a thin marginal fin, extending along the whole back and tail, and as far forwards beneath, as the abdomen. It has a simple, short, alimentary canal, and a series of slit-like branchial openings at the sides of the pharynx, fringed with gill-like processes, constituting the respiratory apparatus. It has no distinct heart; but presents, instead, a series of contractile dilatations of the larger bloodvessels, at the sides of the branchial apparatus. The nervous system which we have here chiefly to consider is composed of a spinal *cord* lying in a spinal canal, above a soft central axis or column, composed of numerous thin discs arranged longitudinally, and forming a true *chorda dorsalis*, or *notochord*. This establishes the vertebrate character of this singular animal. The spinal cord extends along the whole length of the chorda dorsalis; it is thickest in the middle third, pointed behind, and presents anteriorly only a slight bulbous *cephalic enlargement*, but no distinction of parts, like corpora striata, optic thalami, or corpora quadrigemina, much less a separate cerebellum, or cerebrum, and, so far as is known, no folding over of nervous substance, to form a cavity or ventricle. From the sides of the cord, about fifty-five or sixty pairs of nerves are given off, not by double but by *single* roots. The first pair of nerves, exceedingly minute, supply the membranous parts of the mouth. The second pair give off long dorsal and ventral branches, which run backwards nearly the whole length of the body, joining the extremities of the anterior and posterior branches of the other spinal nerves. There are no distinct olfactory nerves, but there exists a median concave *ciliated spot*, in close connection with the fore part of the cephalic bulbous enlargement, which is believed to be the organ of smell; the optic nerves are represented only by two short processes, at the end of which is some pigment and a transparent body, thus forming two simple eye-spots; no auditory apparatus or nerve has been detected. The first pair of nerves, just now mentioned, have been considered functionally to represent the fifth cranial, and the second pair the pneumogastric nerve. The spinal cord consists almost entirely of nerve-cells of a spherical form; they are disposed in a linear manner in the middle third of the cord, but elsewhere, they have an irregular and perhaps segmented arrangement; pigment exists in some of these cells. The white nerve-fibres are indistinctly tubular. No trace of a sympathetic system has been yet described in the Amphioxus. Had not so simple a form of the vertebrate cerebro-spinal nervous system been actually seen, it would have been difficult to suppose its existence. One is naturally tempted to compare it with the nervous system of animals still lower in the scale, especially with that of the Annulosa. But the homologies between it and them are not easily traceable; however simplified, the fundamental plan of its construction follows a different type; the œsophagus does not perforate its anterior portion, and a chorda dorsalis runs between it and the perivisceral or body cavity. This singular animal is not a connecting link between the Vertebrate and the Annulose types. By some, it is considered possible, that it is an embryo condition of a higher form of fish; and, until its development and subsequent life have been investigated, it may be permitted to doubt the specific character of this highly interesting and apparently archetypal animal.

On examining physiologically the actions of animals lower in the scale than the Vertebrata, the proper psychical faculties entirely disappear, as well as the distinct cerebro-spinal form of the nervous system. The anatomical arrangements of the nervous system, in the several lower subkingdoms, are given in the chapter on the general characters of those subkingdoms (pp. 108–112). In even the highest of these non-vertebrate creatures, as in the higher Mollusca and Annulosa, the cerebral *hemispheres*, properly so-called, are probably no longer represented, although the *cephalic* ganglia of these animals are frequently designated *cerebral*. In all the non-vertebrate forms of animal life, intelligence, emotion, and even ideation are wanting; a feeble perception, and volition, may exist in some of the so-called social insects, viz., in the wasps, bees, and ants; but sensation is their great guiding principle. The so-called *Instincts*, which are really the outward expression of *sensori-motor impulses* excited within their nervous apparatus, assume the control of all their acts, even when these, as in the case of the social insects, seem to us to be adapted to new or unusual conditions of existence. Intelligent acts, characterized by improvability through experience, by the varying adaptation of means to ends under altered conditions, and by the use of different means, to accomplish at will the same ends, are now replaced by instinctive acts, exhibiting a sameness in all individuals of the same species, at all ages, and under the same conditions, as well as a uniform perfection, quite irrespective of previous trial, experience, or education. These instinctive acts are performed through the agency of a sensori-motor nervous apparatus, duly stimulated, and physiologically homologous, if not anatomically so, with the sensori-motor ganglionic nervous centres and accessory nerves, found in the Vertebrata. The cephalic ganglia of the non-vertebrate animals constitute the sensorial centres, and represent functionally, therefore, the sensory parts of the vertebrate cerebro-spinal axis; whilst excito-motor ganglia, few or many in number, as the case may be, together with the commissural cords connecting them with the cephalic ganglia, represent functionally the medulla oblongata and the spinal cord. The anatomical homologies of these parts are not yet accurately determined. It has, however, been argued that not only are the cephalic ganglia of the non-vertebrate animals, the *sensorial centres*, the seats of conscious sensation, and therefore of the instinctive sensori-motor impulses, but that, to a certain extent, in the highest forms, they must exercise not only the faculty of perception, in the recognition of the relations between the images produced in the sensorium, and the external objects which cause them, but also an imperfect form of volition; otherwise the lives of these beings must be passed, without their experiencing anything more than mere bodily pleasure and pain, and they could not exhibit that feeble manifestation of will, which they display in the selection of materials for building purposes, in their search after food, and for the companionship of their own species. Besides the sensori-motor acts and apparatus, there exist also in these animals, in very great perfection, excito-motor parts of the nervous system, by means of which many of their movements, particularly those of locomotion, complicated as they are in many species, especially in the case of Insects and Myriapods, are essentially governed, not only without volition, but often even without conscious sensation, as a guide, as is proved by experiments to be presently mentioned; such movements are performed, in the higher examples, through the intervention of those ganglia and nerves, which correspond functionally with the *medulla* and *spinal cord*, although, as just stated, the anatomical homology between them is not so evident. Lastly, certain portions of the nervous centres and nerves are undoubtedly concerned in the regulation of the nutritive or vegetative functions, sometimes, perhaps, acting indirectly through the vascular apparatus, but sometimes directly on the nutritive processes themselves. Corresponding in function with the *Sympathetic* system of the Vertebrata, these parts in the lower animals are but slightly developed, and are only seldom, as in Insects, distinguishable from the rest of the nervous system, and even then, cannot be compared anatomically with the vertebrate sympathetic nervous system.

We may now briefly consider the functions of the different parts of the nervous system in the several non-vertebrate subkingdoms.

Mollusca.

The *cephalic* ganglia, consisting, in the typical forms, of the supra-œsophageal and sub-œsophageal ganglia, sometimes also including a distinct buccal ganglion, and, in the Cephalopods, other ganglionic masses connected with the olfactory and optic nerves, receive all the nerves of special sense, which may be present in any one case, and probably also those of common sensation, and thus constitute the central sensorium, both special and common; they are analogous to the sensorial ganglia at the base of the vertebrate cerebrum; they are sometimes named cerebral, and are the only parts which can be so regarded. It is believed, however, that the cerebral hemispheres are not here represented; but, at the same time, any perceptive powers or will, which the higher Mollusca exhibit, must be manifested by virtue of these cerebral ganglia. They receive branches from all the other ganglia, including the pedal and parieto-splanchnic, an arrangement which probably enables them to receive impressions calculated to excite their *sensori-motor* channels of action, and to regulate the movements of all parts of the body. In the Lamellibranchiate Molluscs, which are acephalous, there are no cephalic organs of special sense, the chief ganglia are quite simple, small, and placed near the mouth, and the movements exhibit no volitional character. In not even the highest Molluscs can we imagine that memory, emotion, or intelligence exist.

The *pedal* ganglia, usually forming only a single pair, but in the Cephalopods much subdivided and scattered, are probably excito-motor nervous centres, and purely reflex; they govern many of the locomotive acts, and represent one of the segments of the spinal cord of the Vertebrata. The surface of the so-called foot may be stimulated through impressions on afferent nerve-fibres, and these may excite the reflex motorial impulse through the pedal ganglion and its efferent fibres. Like the spinal acts in the Vertebrate animals, these reflex locomotive movements in the Mollusca, are, however, subjected to the control of the cephalic ganglionic centres, which, through the longitudinal commissural fibres, exercise a consensual, if not a weak volitional influence over them, as in the spontaneous search after food. The locomotive acts of these creatures are all sluggish, but more or less concatenated. It is remarkable, that the auditory organs of the Mollusca, where they exist, are usually attached, by their nerves, to the pedal ganglia; but the nerve-fibres probably run on, past these ganglia, to the cephalic sensorium.

Lastly, the *parieto-splanchnic* ganglia usually forming a single pair, but sometimes more numerous, supply not only the sides of the body and mantle, but also the respiratory organs (usually branchiæ), and the heart, as well as the digestive viscera; it is by these that the movements of deglutition and respiration are governed, and that the action of the heart is regulated or influenced. But these ganglia are also placed under the control of the cephalic ganglia, especially by commissural bands, which join the cords running on the sides of the œsophagus, from the supra- to the sub-œsophageal ganglionic masses; hence, these cords, with the parieto-splanchnic ganglia, are said to represent functionally, the tracts of the medulla oblongata. These ganglia probably serve as centres for any sympathetic nerve-fibres which these animals may possess.

Molluscoida.

These are simplified Molluscs, and the single ganglionic mass which constitutes their chief nervous centre is probably at once feebly sensory, sensori-motor, and reflex. It represents the three kinds of ganglia in the Mollusca; it sends nerves to a ciliated sac, believed to be a sensory organ, and sometimes has a pigment mass or supposed eye-spot upon it; it also supplies branches to the tentacles in the Polyzoa, and others to the body and viscera. In position and connections, however, it rather resembles the pedal ganglion of the Mollusca, and, like it, its office is essentially excito-motor or reflex. The locomotive acts of these animals are extremely limited, most of them being fixed, or merely borne about in the sea; the most active motions which they present are those of the sides of the body, intended to aid in the drawing in and expulsion of water for the purpose of respiration.

Annulosa.

The nervous system of these animals might be compared with that of the typical Mollusc, by supposing the pedal ganglia of the latter to be multiplied by the addition of numerous other pedal ganglia behind them, according to the number of segments in the Annulose animal; or, in other words, the Molluscous nervous system is like that comprehended in the cephalic and second pair of ganglia of the Annulosa. But the sympathetic system here receives a peculiarly diffused development.

The functions of the *cephalic* or *supra- and sub-œsophageal* ganglia in the Annulosa are also precisely similar to those of the Mollusca, being sensory, sensori-motor, and, in the higher or social insects, perhaps feebly perceptive and volitional. With these are connected the optic nerves, which are, for the most part, very large in the Insecta and Crustacea, in correspondence with the highly developed eyes of these animals; also the smaller nerves from the antennæ or organs of touch, and from the antennules, supposed to be the seat of the sense of smell; the nerves of the auditory organs, where these exist, and however distant they may be from the head; and lastly, the nerves of common sensation from all parts of the body and limbs. Afferent and efferent fibres likewise end in and spring from these ganglia, proceeding to the head, the segmented trunk, and the limbs, and officiating in the various and extraordinary consensual, instinctive movements exhibited by the highest of these animals, especially by the spiders, ants, and bees, in the construction of their webs, nests, and cells, and in the volitional acts implied in any special movements, particularly when they are subjected to unusual or opposing circumstances.

The series of ganglia peculiar to these animals, which are connected together, forming the *double ganglionated cord* found on the abdominal aspect of their segmented bodies, are the locomotive ganglia, corresponding in function with the pedal ganglia of the Mollusca; they constitute the excito-motor reflex centres for the locomotive acts, which, in these animals, as in the various insects, spiders, and myriapods, and even in the swimming crustacea, are probably essentially automatic, and performed independently of sensation, though they may be associated with it, and are independent of volition, although they may often be controlled by it. The ascertained structure of this ganglionated nervous cord, corresponds entirely with these combined functions; for some of the fibres of the roots of the nerves which arise from it, are seen to end in the gray matter of the ganglion of their own segment, or to pass out at the opposite side, or at the same side, often becoming, as demonstrated in the leech, connected with processes from the nerve cells; other fibres pass from the nerves of one segment up and down, along the cord, through one, two, or even three adjacent ganglia, and then pass out into as many corresponding nerves of the same or of the opposite side, above and below; other fibres proper to the cord, act as short longitudinal commissural fibres, uniting the ganglia of adjacent segments, and joining the first ganglionic masses to the cephalic ganglia, those cords which pass by the œsophagus being compared to the medulla oblongata; lastly, fibres are met with sometimes, named *transcurrent*, which pass over the several ganglia, and form longitudinal tracts, extending upwards to the cephalic ganglia. By these last-named fibres all parts of the system are brought into subjection to the chief or cephalic apparatus; whilst, within itself, every segment with its ganglion and nerves can act, either independently or in combination with other segments. These anatomical facts present a sort of analysis of the arrangements believed to exist in the more complex spinal cord of the Vertebrata, which is supposed to consist of independent centres, fused together by continuity of the gray matter; functionally and structurally we here recognize a homology, though, as already mentioned, there is, as yet, no evidence that the double ganglionated cord of the Annulose type is the anatomical homologue of the spinal cord of the Vertebrate type. Experiments have demonstrated most conclusively that this part of the nervous system of an Annulose animal, consists of independent and purely reflex centres, and that they yield phenomena precisely similar in character to, but even more striking than, those presented by lizards, frogs, and newts. Thus, a decapitated insect, nay, even a single segment of a centipede, continues to perform symmetrical and characteristic movements when it is irritated, or placed in such a position as to be stimulated to action; a water-beetle, for example, if beheaded and then placed in water, will perform natatory movements. When, however, portions of an Annulose animal, severed from their connection with the cephalic ganglia, are left untouched, or are not subjected to any special stimulus, they remain quiescent and immovable. Moreover, though a decapitated centipede will, if irritated, continue an onward movement and push its headless trunk against any opposing body, it will not mount over it, turn aside, or move backwards, as it would do if still under the guidance of sensation and a low form of volition; it cannot adapt or suit its movements to the nature of the obstacle or impediment placed in its path. The multiplied feet of these animals demand a corresponding multiplication of the ganglionic reflex excito-motor centres, but they are made to act harmoniously, in succession and in alternation, on the two sides, which pass from nerve to nerve, and from one segment of the cord to another; whilst, in the perfect animal, all are brought into harmony, either instinctively or volitionally, by the transcurrent cephalic fibres. The government of the remarkable locomotive powers of these animals is thus provided for, their active respiratory functions and other nutritive processes assisting and giving them the requisite muscular irritability, whch is so striking when contrasted with the slow movements of the Mollusca.

Instead of the parieto-splanchnic ganglia of the Mollusca, there is found, at least in the higher Annulosa, a very remarkably complete sympathetic system. Even from the cephalic ganglia two minute filaments are given off, which speedily unite to form a single cord, on which a minute ganglion is found; and from this, branches proceed to the alimentary canal, the dorsal vessel, and the adjacent large tracheæ; from the commissural bands or tracts between the several ganglia, similar nervous filaments arise, which unite, are connected with a minute ganglion, and give off branches chiefly for the dorsal vessel and tracheæ of particular segments. These minute ganglia and nerves must govern, like the sympathetic system of the Vertebrata, the vegetative processes of the animal, viz., those performed by the alimentary canal, the glands, the dorsal vessel, and the tracheæ.

The nervous system of the Annulosa, is modified, so as to be adapted to the varieties of form in the heads and bodies of the different classes or groups. Thus, the development of the cephalic ganglia, corresponds exactly with that of the parts situated on the head, and of the organs of the senses, especially of the eyes. Again, the number, size and degree of concentration, of the series of abdominal ganglia, correspond with the number of the segments in the body, their size, the degree of development of their attached limbs, and the mode in which two or three segments are sometimes fused together. In the tailed Crustacea, as in the lobsters, shrimps, and others, the thoracic segments are consolidated, and the thoracic ganglia are concentrated into a single large mass, placed at a considerable distance from the cephalic ganglion, the connecting commissures between which are therefore unusually long; this thoracic ganglion supplies the nerves to the claws and feet; the abdominal ganglia, in accordance with the length and subdivisions of the trunk, are numerous and separate. On the other hand, in the tailless Crustacea, as in the crab tribe, in which the body is mainly composed of the wide and consolidated thoracic segments, and the abdomen is, as it were, atrophied, the nervous system consists of a cephalic ganglion,placed in the head, and connected, by the usual commissural nerve cords, with a single thoracic ganglionic mass, in which, all the locomotive ganglia are concentrated, and from which the nerves radiate to the several feet; in this most perfect example of the concentration of the inferior ganglia, the resulting nervous mass may be aptly compared to a Molluscous pedal ganglion. In the Arachnida, or spiders, the inferior portion of the nervous system, is also remarkably concentrated, there being usually a large thoracic ganglion, and a large single abdominal ganglion. Finally, in the Myriapoda or Centipedes, the nervous system, in accordance with the repetitive segmentation of the body, the number and equality of its component segments, the absence of any specially developed locomotive members from any one segment, and the presence of numerous members of nearly equal development upon all the segments of the body, presents a great number of abdominal ganglia, a pair being found in each segment of the trunk, differing, but little in size, one from the other.

Most remarkable instances of the pliability of organic types, may be seen in the singular modifications of the nervous system of the same individual insect, during the metamorphosis which the true insects undergo, from the larva or caterpillar state, to the pupa or chrysalis, and then to the imago state. In each of these changes, the nervous system participates. Thus, in the caterpillar, or grub, in which the segments of the body are always more numerous than in the perfect insect, the number of the abdominal ganglia is increased accordingly; and, as these several segments in the caterpillar, are of nearly equal importance, and equally developed, the ganglia are of nearly equal or uniform size. Moreover, as the organs of special sense, of which the eyes are still the most important, are comparatively feebly developed, the cephalic ganglia or special sensorial centres, are relatively small, and present no marked preponderance over the abdominal ganglia. The locomotive powers of the caterpillar, or grub, are also singularly limited, in comparison with those of the perfect butterfly or beetle; and such combining and controlling power, as is necessary to bring the locomotive movements into harmonious action, is, of course, of feebler character; hence the small relative size of the cephalic ganglion. In the chrysalis stage, in which preparation is already being made for the development of the perfect insect, suitable modifications in the nervous system begin to take place; these consist, first, in a concentration of some of the longitudinal chain of ganglia, especially of those corresponding with the thoracic region, now and hereafter to be developed as the basis of support, not only of the lower limbs, but also of the wings, and containing the large muscles which move those members; secondly, in an actual wasting, or disappearance, of some of the abdominal ganglia, in accordance with changes, or abortions of the segments themselves; and lastly, in an increase in the size of the cephalic ganglia, harmonizing with the foreshadowed increased development of the sensory powers, of the sensori-motor or instinctive faculty, and of such volitional manifestations, as the perfect insect is capable of. In the perfect insect, these changes in the nervous system attain their full development; the cephalic ganglion, the great sensory centre, and controlling motor centre, assumes a preponderating size, in comparison with the other ganglia; the thoracic pairs of ganglia are enlarged and concentrated; whilst the abdominal ganglia remain small, or even diminish in size posteriorly.

Annuloida.

The quadruple, double, or single cephalic ganglion of the vermiform Scolecida, or Rotiferous animalcules, undoubtedly combines the sensory and the sensori-motor powers, and the reflex faculty as well; but there is no evidence of real volition in these animals. It has connected with it, the nerves of the tentacles, and those of certain ciliated, and possibly sensory, sacs, and resting upon it, in some cases, are pigmentary eye-spots, or rudimentary ocular organs. The Rotifera, at all events, seem to be attracted by light and heat. Passing backwards from the cephalic ganglionic mass, are also nerves, which supply the skin, the muscles of the body, and even the viscera. The nervous system of the Echinodermata, is very peculiar, being adapted to the radiated condition of the body; its several ganglia may be regarded as parts of one divided cephalic ganglion connected by commissures; from its five segments, afferent and efferent fibres proceed to the rays, or divisions, of the animal, to the mouth and viscera; the eye-spots, found in some star-fishes, also have minute nerves traceable to them. There is certainly no sign of volition in the Echinodermata; their sensation is also of the lowest order; and the sensori-motor, or instinctive, movements are probably almost entirely replaced by purely excito-motor, or reflex acts, which would almost explain their habits and life. None of the five ganglia are larger than, or exhibit any superiority over, the rest; they may be regarded as presenting an example of a subdivided locomotive or Molluscous pedal ganglion, with but a slight share of sensibility superadded. Moreover, the ganglia are connected by some physiological, as well as anatomical, bond; for, in the Synapta, a species of star-fish, which has the habit of casting off, at its base, an injured or irritated ray, this power is lost, if any part of the nervous circle around the mouth, be previously cut through.

The functions of the sympathetic system, seem to be performed by the general nervous system, or by parts blended with it; for no distinct ganglia appear to be set aside for it.

Cœlenterata.

In the few instances, in which a distinct nervous system has been detected in this subkingdom, as in Beroe and Cydippe, its ganglionic central mass has a spot of pigment upon it, and gives off nerves to the soft contractile walls of the body, and to the so-called auditory sacs. It must fulfil a sympathetic and reflex office; it may also exercise the feeblest sensory or sensori-motor power; but no volitional functions. It is possible, that in the simplest forms, such as the Hydra, no nervous system exists; it is more probable, however, that it is present, but has escaped detection. Lower than this, we cannot imagine, on physiological grounds, the presence of a nervous system, which controls movement; for, without one afferent, and one efferent, fibre, and a connecting nerve-cell, we cannot well understand how nerve-substance can exercise any governing influence over muscular fibres, contractile cells, or sarcodous substance. Without these three elements at least, the muscular substance probably contracts by direct stimulation of its fibres, and the resulting movements would be *irregular* and indeterminate. The supposed admixture of nerve-cells, with the other tissue elements, or of nervous granules with the cell-contents of the uni-cellular animals, might still, however, have for its office, some feeble sensorial function, or the regulation of the nutrition of the tissues, in some manner unknown to us, but analogous to that of a sympathetic system.

Protozoa.

In this, the lowest subdivision of the animal kingdom, so far as microscopic research has extended, and so far as physiological inference may be our guide, a nervous system, consisting of nerve-cells and nerve-fibres, cannot exist; and the idea, already alluded to, of the presence of nervous granules in their substance, is, of course, hypothetical. The Infusoria, which are uni-cellular animals, that is, composed of a single organic cell, and which are moved entirely by the action of cilia on their surface, may well be understood to require no motorial nervous apparatus to govern their movements, seeing that the ciliary motion, even in the higher animals, is independent of nervous influence. It is certain, however, that Infusorial animalcules, kept in a vessel of water, will congregate towards the light; and in some of these minute organisms, colored spots present themselves, which, if they be ocular spots, would imply some feeble form of sensation. A granule, or particle of nerve-substance, situated at some particular point, within this single-celled animal, might form an excitable sensorial nerve-centre, without exercising any controlling motor influence. In the Rhizopoda, or Foraminifera, and in the Spongida and Gregarinida, all of which consist of a fleshy or contractile sarcodous mass, not enveloped by any distinct cell-wall, and the shape of which may, in the two former groups, change most irregularly, it would seem as if the contraction of the sarcode, on which the movements of these primitive animals depend, were excited directly by external stimuli, acting without the intervention of nervous substance. Their motions can scarcely be said to possess the spontaneity and regularity which are characteristic of those dictated by or excited through, a nervous system, and which therefore are characteristic of animal life. They resemble more, those performed by the parts of plants, or by some of the lower plants, in which the co-operation of nervous substance is not even suspected.

If these lowest forms of Protozoa possess any nervous granules within them, they are probably not even sensory, for no trace of ocular pigment is found in them; such granules might, however, exercise a control over the nutrition of the cell, and in this way, indeed, might influence ciliary motion, not only in the Spongida, but in the Infusoria, in the Cœlenterata, and in all the higher animals, even in the Vertebrata; for that motion may be intimately connected with, if not wholly dependent on, nutritive molecular changes.

THE SENSES.

Sensation in general.

Sensation consists essentially in a certain change in the sensorium, or the sensorial portion of the cerebrum, accompanied by the mental state known as consciousness. By this we become aware of external or internal impressions made upon the sensory nerves, or rather of certain conditions of those nerves produced by those impressions. The consciousness of these central changes, produced within us by means of such impressions, constitutes sensation. Changes, originating in the sensorial centres, may also induce internal sensations. Hence, in the act of sensation, whether from external or internal causes, we feel the condition of our nerves and nervous centres, and not the objects or stimuli which excite them.

The ultimate evidence of the existence of sensation, in each individual, is intrinsic and personal. Conscious sensation is a fact, in the constitution of our corporeal and mental nature, which is absolutely incapable of explanation. The evidence of sensation in other persons is a matter of inference from likeness of organization and similarity of behavior under like impressions; or it rests on testimony as to what they feel. The sensation of others, and their identity with, or similitude to, our own, can neither be known nor demonstrated; they can only be inferred or assented to. As regards animals, the existence in them, of sensations, whether common or special, is merely inferable from the facts of their organization and their conduct. Many of our ordinary sensations are composed of sensations associated with certain ideas or judgments.

The conditions of sensation are *anatomical*, *physiological*, and *causal*. First, there must exist a sensitive surface or organ, to which the peripheral extremities of the sensory nerve-fibres may be distributed; secondly, such sensory nerve-fibres; and, thirdly, a sensorial gray nervous centre; moreover, these several parts must be in anatomical connection with each other. Such parts, for example, are the eye, the optic nerve, and certain portions of the cerebrum. Even where, as in the exceedingly simple eyes of some of the lower animals, the ocular spots are placed close upon the nervous ganglia, there are doubtless extremely short connecting nerve-fibres between them. Secondly, the physiological conditions of sensation are, the healthy state of the several specially endowed anatomical organs, a due supply of arterial blood to those parts, and an active state of their nutrition; for, if they be either fatigued or inflamed, over-excited, exhausted, or atrophied, sensation is modified, or even suspended. Abnormal conditions of that part of the sensorium which is concerned in any particular sensation may cause increased or diminished sensibility to external or internal impressions. Lastly, the several parts just enumerated as constituting a complete sensorial apparatus, must be excited by some causal agent, known as a *stimulus*, which, in the ordinary acts of sensation, induces a change in the nerves, and through these in the sensorial nervous centres, but which, in the case of internal sensations, may act either on the nerves or directly upon the nervous centres.

Sensory stimuli are said to be either *external* or *internal*, according as they proceed from without or from within the body. The former have also been named *objective* the latter *subjective;* but, as elsewhere already mentioned, even internal stimuli are equally *objective* in reference to the *mind*, which is, in the metaphysical sense, the real subjective element of our nature: to this, the body, and even the nervous system, and the sensorium itself, are truly objective, and stimuli proceeding from them are therefore likewise objective, though internal or corporeal. The ordinary *external* objective stimuli are physical, material, or mechanical, chemical, thermal, or electrical, and include matter of all kinds, all forms of motion, molar or molecular, undulatory or impulsive, such as those which produce sound, heat, perhaps chemical action, light, and electricity. Such motions, succeeding each other according to fixed laws, may be supposed to be propagated onwards, through the sensory apparatus, or to produce corresponding motions, molar or molecular, in it. The *internal* or corporeal objective stimuli reside in the blood, such as its temperature, and peculiarities in its chemical composition; or they may proceed from the tissues to which the nerves are distributed, changes in the nutritive metamorphosis of which may affect the nerves; or they may depend upon changes in the nutritive condition of the extremities, or of the trunks, of the sensory nerve-fibres, or of the sensorial nervous centres themselves. The sensations resulting from such stimuli are commonly known as *subjective*. But, as we have already mentioned, the only true subjective stimuli which can cause sensations are those depending on purely psychical or mental states, such as ideas or emotions. It is often difficult, in regard to certain sensations, to say whether they are corporeally or externally objective; also whether they are truly subjective, corporeally objective, or externally objective. Experience and close examination can alone decide these points. Sensory stimuli have also been defined, according to whether they are able to produce only one kind of sensation, or several different kinds, as either *homologous* or *heterologous*. For the reception of the former, such as light and sound, the sensory organ requires to be peculiarly constructed, and the nerve to be specially sensitive at its extremity. The latter, such as electricity or mechanical shocks, produce various forms of sensation, and act on all kinds of sensory organs. The sensations produced by either kind of stimulus are similar for each organ. A homologous stimulus acts only on its proper nerve; light, for example, has no effect on the nerves of taste; moreover, such a stimulus acts only on the periphery of the nerve-fibres, and not upon their trunks, as is illustrated by the fact that the optic *nerve* itself is insensible to light. As different stimuli, acting on the same sensory organ, give rise to the same kind of sensation; and again, as the same stimulus may produce different sensations, if it acts on different organs, it would appear that each sensory apparatus has its own recipient power or endowment, perhaps likewise some special energy in its nerve, and, as is generally supposed, in its proper sensorial nervous centre. Hence, an absolutely deaf person cannot hear even the loudest sonorous vibrations; but he may perceive them, through the sense of touch, as physical vibrations of matter.

Certain general facts, in regard to sensation, have been described as laws of sensation. For example, in the ordinary act of external objective sensation, the surface of the sensory organ is the immediate recipient of the stimulus, and, through it, the first impression is made on the peripheral extremities of the sensory nerve-fibres. These latter, then, play an internuncial part, and conduct the changes induced in them, to the sensorial nervous centre, which itself undergoes changes, being the excitable anatomical seat of what is known to our consciousness, as sensation. The presence and the degree of sensibility in a part, depend, other things being equal, on the existence and the number of nerve-fibres distributed to it; thus parts and tissues destitute of nerves, such as the nails, hairs, and cuticle, are absolutely insensible; the tendons and bones, which have but few nerves, are but moderately sensitive, excepting in cases of disease; whilst the skin, lips, and tongue, are highly sensitive, being provided with an abundance of nerve-fibres. Stimuli act especially, and most easily and effectively, on the extremities of the nerve-fibres.

Each point, or definite part, of a recipient sensory surface is independent in its action, as regards all other points or parts; and so there must be corresponding points, or parts, in the sensory nervous centre; otherwise there could be no distinctness of local impression, on which depend, to a great extent, if not entirely, the accuracy of certain sensations, for example, those of touch and sight, and also the power of comparing different, or repeated similar sensations. The independence of the nerve-fibres, in their course from the sensory organs to the great nervous centres, is supposed to account for this independence, so far as regards the internuncial nerve-cords.

Another interesting general fact, concerning sensation, is, that the mind, *i. e.*, the mental perception, refers sensations not to the sensorial centre, or actual seat of conscious sensation, but either to the stimulated part, or seat of the primary impression, or even to the outer world. Thus the prick of a pin, is at once referred to the skin, and not to the sensorial portion of the cerebrum, where the sensation is completed; and, again, the impressions which produce the sensations of taste and smell, are also located in the tongue and nose. The sensations belonging to hearing and sight, are likewise not felt in the brain, and only appear to take place *through* the ear and eye; but they are referred exclusively, to their external causes, outside of, and more or less remote from, the body. It is also to be noted, that touch, taste, and smell, are excited by bodies of various kinds, whilst hearing and sight are stimulated, each by one special agent. The reference of sensations to the peripheral extremities of a nerve, even though this be stimulated in its trunk, is illustrated by the tingling of the little finger, or the feeling of pins and needles, when the ulnar nerve is struck, or compressed, at the elbow, or *funny bone;* and the same phenomenon is observed after amputations of the limbs, when sensations are felt, as it is expressed, in the amputated toes or fingers, owing to irritation in the cut ends of the nerves of the stump. This local reference of the sensations, to the extremity of the nerves concerned, is also exemplified in the phenomena of the transference and radiation of painful sensations (see page 274).

The nature of some sensations, as we have just shown, is so purely objective, that we habitually refer them entirely to the outer world, without being conscious of any internal or local changes in the sensory apparatus; this is the case in sight and hearing. A less completely objective sensation is that of pressure, since we refer it to a part of the body, as well as to its external cause. Still less apparently objective sensations are smell, taste, and the thermal sense; for these are referred entirely to the nose, mouth, and heated or chilled surface of the skin, and not to the outer world. The reference of these three degrees of objective sensations, to their respective external causes, is connected with different mental processes; but, in all cases, an inference is drawn, that they depend on properties of external objects or forces. Thus an agreeable odor is a property of the rose, and a green color of chlorophyll. At first, however, in the infant, sensations are not associated with ideas, or related, through perception, with external objects; but the mind, by some innate process, soon compares sensations, caused by such objects, with those which arise in the interior, and learns to discriminate them from the latter, and so to distinguish the objective "self," from the outer world. The recognition of the subjective "ego," is a still higher mental act.

Though sensations are, in the normal condition, inseparably linked with consciousness, they may be unattended to, or cease to be regarded by the attentive mind, *i. e.*, by the mind acting in the state called *attention;* the sensations are then so transitory, that they have been named, though, it is here submitted, erroneously, *unconscious sensations*, a concatenation of terms, apparently illogical, and contrary to fact. In the most perfect sensation, the whole attention must be concentrated upon the sensory impression.

The *velocity* of sensory impressions, in their paths from the peripheral organs to the sensorial nervous centres, has been already mentioned (page 223). This velocity is measurable, but so rapid, that, within the limits of the body, the moment of sensation practically coincides with the moment of impression. The *intensity* of a sensation, is proportional to that of its exciting cause, the state of the sensorial apparatus being equal; but we are unable to perceive any measurably corresponding strength, in the sensations produced; as, for example, in degrees of flavor, or shades of brightness. The impressions made upon the senses of touch and sight, however, yield us definite measurements of space and time. The relative *acuteness* of sensation, is determined by the ability to distinguish the feeblest stimuli, or stimuli differing but very slightly in intensity. Weak stimuli require a longer period of action than strong ones.

The apparent *duration* of sensations, varies in the different senses, and is also influenced by the state of the nerves concerned; thus, the duration of impressions *photographed* on the retina, is sufficiently long, to enable a luminous circle to be produced by whirling a point of light through the air, and doubtless explains the streaming lights seen in artificial fireworks, and the track of light which a meteor, or falling star, leaves behind it; but the duration of light on the retina, is limited, otherwise one set of images would habitually blend with preceding or succeeding ones, as the eye shifted its direction. Again, the duration of auditory impressions is undoubted, but not practically sufficient to interfere with the function of hearing. The impressions of smell, and especially those of taste, are more durable, probably, however, because the odorous and sapid particles, which excite them, are not removed, but continue to act on the sentient extremities of the nerves. The duration of sensory impressions on the skin, depends chiefly, on the length of time, during which the particular stimulating body has been applied to it; the instantaneous prick of a pin leaving an evanescent sensation, whilst the longer contact of the same body is followed by a more lasting effect. Sensations occurring in debilitated states of the health, or in weakened conditions of the nutrition of the nerves and nervous centres, are more durable than those occurring in the healthy state; in the latter case the nutrient effort of the nervous substance more quickly restores it from the peculiar condition of change produced by its stimulation.

After-sensations, more or less distinct, are noticed in regard to all the senses. They depend on the persistence of the disturbed state of the sensory apparatus, nerve, or sensorial nervous centre, which parts are not immediately restored to a condition of rest or equilibrium. These after-effects endure longer in enfeebled states of the sensory apparatus, or in debilitated states of the nervous substance, as illustrated in the case of ocular *spectra*, which remain longer on the retina in persons in whom that part of the eye is enfeebled by age or other causes. Ocular spectra recur, as well as persist.

Certain sensations are accompanied by other or *associated* sensations. These arise either from simple radiation of the same sensation, as in the extension of a luminous impression on the retina, and the diffusion of a painful sensation through inflamed or excited nerves, as in neuralgia of the face from toothache; or from the excitation of a different sensation, as when a cold or creeping sensation is caused along the back, or the teeth are set on edge by disagreeable jarring sounds, like that produced by drawing a slate pencil vertically upon a slate, or by tearing silk or calico.

The *repetition*, if moderate, of a sensation, has the effect of strengthening the power of the sensory organ, nerve, or centre, or of all three parts. This is illustrated by the exercise of a particular sense, as, *e. g.*, of the eye by sailors, of the ear by the practised musician, of taste and smell by wine- and tea-tasters, and of the sense of touch by watch-makers, silk-weavers, and others. But the too frequent repetition of powerful sensations exhausts part of, or all the sensorial apparatus. It is also to be observed, that whilst the repetition of the same sensory impressions may strengthen the sensory faculty, it at the same time weakens the power of attention to such sensations, especially if these be monotonous, like the ticking of a clock, or the clack of a mill; and thus persons become habituated to sounds, and also to continued odors, whether agreeable or disagreeable, without attending to or perceiving them.

The *alternation* of different sensations, or of sensory impressions of the same kind, but differing in degree, is a most effectual mode of educating the senses.

Remarkable individual peculiarities, quite within the limits of health, are observable in different persons, as regards their respective powers of sensation. Some of these may be due to education, training, or habit; but many are only to be explained by reference to individual peculiarities of endowment. For example, there are persons unable to distinguish certain tones, especially the various intermediate gradations between two musical notes; there are also persons, as we shall hereafter explain, who are unable to appreciate certain colors, and are hence named *color-blind;* and instances of defective smell are likewise met with. National peculiarities of sensation may account for the love of certain colors, and for the special love of music, noticeable in different peoples.

Exaltations of sensation occur in the so-called mesmeric, somnambulistic, or hypnotic states; for in these the senses of temperature, touch and hearing may be acutely manifested.

It is not known whether such peculiarities and exaltations of sensation are owing to modifications in the recipient surface or organ, in the internuncial nerves, or in the sensorial centres. Probably, in the case of individual or national peculiarities, all these parts are modified; but in the so-called mesmeric exaltation the change is perhaps limited to the sensorial nervous centres.

Suspensions of sensation may be produced in several ways: thus, the topical application of cold, ether, chloroform, morphia, or other anæsthetic agents to the sensory surface or organ, may suspend sensation locally. Pressure, ligature, disease, or division of the internuncial nerve, may also interrupt or destroy sensation. Effusions of blood, softening, or other morbid changes in the sensorial nervous centre, are equally fatal to the sensory functions. Narcotics, taken internally, or injected under the skin, and chloroform and ether inhaled through the lungs, also suspend sensation by their general action. There is one natural mode of suspension of the action of the senses, which remains to be mentioned, and that is *sleep*, the influence of which is to be explained by its effects, not on the sensorial surface, or the conducting nerve, but on the sensorial nervous centres or common sensorium. It is said, that under the influence of sleep, sight, the most acute sense, is the first to be suspended, then taste and smell, next hearing, and lastly, touch.

The memory cannot recall common sensations, nor, except rarely, the sensations proper to the special senses; but it can, the mental perceptions produced as the result of these.

The *variety* of sensations manifested by man, is very great, and the ordinary subdivision of these, into common sensation, and five special senses, viz., sight, hearing, smell, taste, and touch, by no means sufficiently or scientifically expresses the whole range of our bodily sensations. In such a classification, the sense of touch is recognized as distinct and special, though more often regarded as a simple modification of the common sensibility. Again, it neglects the distinctive characters of certain other sensations, by including them under the head of common sensation, especially the sense of temperature, *i. e.*, of heat and cold, the muscular sense or the sense of internal effort and resistance, the sensations of hunger, thirst, nausea, satiety, want of breath, fatigue, and exhaustion; and, lastly, the feelings which accompany certain mental states, such as imaginary sensations, and the peculiar sensations experienced in deep emotions, whether pleasurable or painful. From these so-called modifications of common sensibility, the sensations proper to the muscular system have been removed, and treated of as belonging to a special sense, under the name of the *sixth sense*. The researches of Schiff and Brown-Séquard (page 271), have, moreover, led those physiologists to the belief, that special paths of conduction exist in the spinal cord, for the sensations of *touch*, *temperature*, and *pain;* so that perhaps the true tactile sense should be distinguished from common sensation, to which pain may be referred, and the sense of temperature from both.

Special Sensation.

The causes of the *variety* of sensations, whether common or special, are very obscure. Common sensation is the basis of the special sensations, or the fundamental type of sensibility. Touch is plainly a modification of it, and, in this general view, even taste, smell, hearing, and sight, are but special adaptations of a common sensory faculty. The organs of the special senses, even the nose, the ear, and the eye, are formed out of inverted portions of the common surface of the embryo, which, for the development of those specially constructed and complex organs, undergo peculiar metamorphoses, to adapt each for the reception and *translation* of its proper external stimulus, so that this may excite the energy of the nerve and nervous centres. Besides the special recipient apparatus, however, there are special internuncial nerves, and special sensorial nervous centres. Moreover, it is supposed that these nerves have special endowments to suit them for their respective offices, and that the nerve centres possess distinct physiological properties or modes of reaction under external stimulation.

The special susceptibility of each sensorial centre, whether of that of sight, hearing, smell, or taste, is said to be proved by the fact, that internal changes in these centres, may produce corresponding sensations, independently of the co-operation of either the special nerves or recipient apparatus. In cases of amaurosis, or loss of visual power in the retina or nervous expansion of the eyeball, luminous spectra have been excited by internal causes; and galvanism, applied to a person deprived of one eye, has been known to cause luminous impressions on the blind side. But to these facts, it may be objected, that, in the first case, the recipient organ was still connected with the brain, and might not have been altogether disorganized; and in the second case, that the luminous impressions might have been erroneously referred to the blind side, or have been the result of a recurrent action of the sound eye. A common internal stimulus, such as an excess of blood in the capillaries of the nervous centres, is frequently known to produce flashes of light, noises, or odors, according to the sensorial centre affected; but in such cases, it must be remembered that these parts are still in connection with their respective recipient organs. This is also the case, when so-called ocular spectra are seen, some of which are so definite in shape, detail, and color, as to resemble external objects, or persons, familiar to the subject of such spectral illusions, and, indeed, so defined, that we cannot conceive of their production amongst the nerve cells of the sensorial centre, but must refer them to the preliminary formation of definite *patterns* of images upon the retinal structure. The same objection may be made to instances of the sensation of light being caused by pressure on the brain, of sparks, of buzzing or other noises, and of creeping sensations in the skin, being produced by narcotic agents, in all which cases, the recipient organs are still connected with the sensorial nervous centres. The results of the application of a common external stimulus, such as a blow, pressure, or electrical shocks, to the various sensory organs, all of which undoubtedly produce the sensations of light and color in the eye, loud or ringing noises in the ear, a salt or acid taste in the tongue, and shock or pricking in the skin, are open to the same objection. As to the effects of direct stimulation of the trunks of the gustatory, olfactory, or auditory nerves, by electricity or mechanical means, nothing is known; direct irritation of the optic nerve, is said to produce not pain but a sensation of light; no such experiment, however, has yet been made, after the complete removal of *both* eyeballs, and therefore, even if one eye had been removed, some recurrent effects may have been produced through the retinal elements of the remaining eye.

The existence of a special susceptibility in the internuncial nerves of the different senses, is inferred from similar, but equally defective, evidence to that adduced in regard to the supposed distinct endowments of the sensorial centres. It has even been assumed that they possess not only a special irritability as regards certain heterologous stimuli, but special qualities which can generate, under ordinary or homologous stimulation, peculiar sensations in the several sensorial centres; but the proofs adduced are of the same imperfect character; and some disturbance or altered condition of the *recipient apparatus* still in connection with the nerves, may have been the cause of the specific reaction of the nerve and its nervous centre. The well-known phenomenon of sensations referred to the lost toes or fingers, after amputation of the limbs, presents an example of localized sensation, dependent on irritation of a nerve-trunk; but such sensations are not special, or such as apparently require a recipient organ to excite them. They resemble rather the sensation of pins and needles in the little finger, produced by a blow upon the ulnar nerve at the elbow, and consist of modifications of pain rather than of definite tactile impressions, or impressions of temperature, such as can only be produced through the cutaneous organs.

The phenomena of special sensation and its varieties may perhaps be accounted for without assuming the existence of absolutely distinct physiological endowments in the internuncial nerves and nervous centres. The conducting and recipient powers of these may be the same or fundamentally alike; their structure, at least, presents no recognizable difference sufficient to account for any absolute difference of endowment; any disturbance in their molecular constitution, produced by a sensory impression, may be supposed to involve the same vito-chemical and vito-physical changes in the substance and condition of the nervous elements, whether characterized by oxidation, heat, or internal motion; these changes may present merely correlated differences in *kind*, or in *degree*, in regard to each sense; the peculiarities or different degrees of these changes may depend on the difference in the external stimuli which, in the case of each special sense, are able to act upon the nervous substance; and lastly, the object of the specialized recipient surface or apparatus in each sensory organ, the *only* part of each organ of sense in which we can detect most manifest, varied, and singularly adapted structure and contrivance, may be to mediate between the special stimulus and the common fundamental nervous endowment, to translate that stimulus into nervous energy, and so to excite peculiar modes of reaction in a similar nervous substance. When our knowledge concerning the conditions or changes which take place in the nervous substance in common sensation is complete, we may be able to explain the modifications in those changes or conditions which are essential to special sensation.

All sensations, though realized through the mental state called consciousness, which is *beyond our means of investigation*, depend ultimately, as objects of physiological study, on certain corporeal states or changes in the sensorial nervous centres. These changes or states are produced, as we have explained, either by *external* or *internal* stimuli; the external stimuli in question differ remarkably in their source and nature; and there must obviously be a strict correspondence between the variety of reactions in the nervous substance, and the nature of these stimuli. May not, therefore, the differences presented by the various stimuli to sensation furnish us with the means of classifying the sensations themselves? Thus the external stimuli produce distinct impressions corresponding to the sensations of sight, hearing, smell, taste, the tactile sense, and the sense of temperature, all of which may be regarded as distinct senses. Sight informs us of the existence of light and color; the sense of temperature conveys to us the knowledge of the existence of heat; and these two senses would seem to have a certain natural alliance with each other. Again, the senses of smell and taste are also allied. Lastly, the sense of hearing, as we shall immediately show, is closely allied to that of touch. All the senses are excitable by the electric energy.

These six special senses may, according to this view, be arranged in three groups, each containing two related or coupled senses. The first group consists of two *molar* or *dynamical* senses, viz., touch and hearing, the senses of matter in *contact* and of matter in *motion*, or the *tactile* and *acoustic* senses; the former reveals to us the presence of matter itself by the pressure of substance against substance, whilst the latter conveys to us the effects produced by particles of matter undergoing motions which cause the phenomenon of sound. The second group is *chemical*, and includes *taste* and *smell*, the former acting *dialytically*, the latter perhaps *catalytically*. Both depend on chemical reactions, which take place in the extremities of their respective nerves, and are allied by the common property of recognizing those forms of *molecular* motion which occur in acts of chemical combination or decomposition. Taste, however, requires as one of its conditions the dialytic penetration of a chemical substance in solution, through the soft tissues to the extremities of the gustatory nerves; whilst smell appears to require the concurrence of a catalytic act of chemical combination, between oxygen, or some other agent, and the odorous matter, at the surface of the olfactory membrane, to which, as we shall hereafter describe, certain pointed appendages of the olfactory nerves actually reach. Lastly in the third group are contained the *thermic* and the *photic* senses, which convey to us the effects of those further kinds of undulatory movements, occurring between the molecules and supposed *intermolecular* ether, or in the intermolecular ether itself (or in the centres and periphery of those spheres of force, of which matter, by some, is supposed to consist), upon which the phenomena of heat and light are believed to depend,—movements and phenomena so far related, that, though heat may be manifested to us without light, and light without heat, yet heat of a certain intensity is always accompanied by luminosity. These two senses we might group together as the *etheric* senses. So regarded, the six senses may be thus arranged:

Molar or Dynamical senses, . .	Tactile—Touch. Acoustic—Hearing.
Molecular or Chemical senses, . .	Dialytic—Taste. Catalytic—Smell.
Intermolecular or Etheric senses, .	Thermic—Temperature. Photic—Sight.

By means of these senses, all our knowledge of the *matter* and *energy* of external nature is obtained, and all our psychical faculties are called into action. In the absence of the most important senses, indeed, man sinks intellectually below many animals. These six senses necessarily correspond with those properties and actions, physical, chemical, and material, of the world around us, which are cognizable by us, and the effects of which, communicated to special recipient surfaces, must produce, through special mediating and translating apparatus, corresponding changes in the nervous substance. It is now generally believed that all the energic phenomena or manifestations of force in nature, are correlated, or, as it were, capable of transformation into each other: mechanical motion producing heat; heat, chemical action; both, in their turn, light, and so on; so that, according to this view, the photic, thermic, chemical, and mechanical stimuli in nature, are all correlated. In the same way, is it not probable that, to receive, react against, and feel these various forms of correlated stimuli, there may exist in the nervous system but one common functional excitability, or one common and essential nervous energy, to be excited by these stimuli; and if all active physical effects are to be traced to different modes of motion, in the molecules or intermolecular ether, in external, dead, *non-nervous* matter, may not all nervous action, concerned in sensation, likewise depend upon different molecular and intermolecular modes of reaction, in internal, living, *nervous* matter?

On this, or some similar view, of a *harmony* between the physical phenomena of external nature and the nervous reactions excited within the sensorium, can we alone believe in, or explain the possibility of our attaining accuracy and fixedness of knowledge concerning external objects and phenomena; for without such internal and external correspondences, no real knowledge would be possible, and certainly no community of knowledge, ideas, or thought, between different individuals or generations, could exist.

Concerning the *completeness* of the human senses, in regard to external nature, no certainty can ever be attained; for, if there be agencies in nature, other than those which now produce sensations within us, it is impossible to prove their existence, unless our organization were so changed as to enable us to perceive them. It is, however, as unphilosophical to suggest a limit to the number of modes of action of the common force of nature, as it is to assume the existence of such modes as we cannot possibly establish by proof; for we cannot deny the existence of other modes of action of the force of nature, which may be unperceived only because they are imperceptible to us. But the mind naturally inclines to a belief in a certain completenes in the series of our senses, and in the harmony established between them and the modes of action of the common energy of external nature. Moreover, there is reason to believe that the nervous energy manifested in nervous reaction, is itself correlated with that common force.

With regard to the possibility of the possession of *additional* external senses by animals (for no one believes them to possess additional internal senses), it may be stated that this is a question beyond our means of investigation. However, as a conclusion, based on general considerations, Man, being undeniably the most highly organized creature on the earth, it is highly improbable that the nervous systems of any of the animals lower than himself, are endowed with special sensorial powers, enabling them to recognize modes of action of the common force of nature, which pass undetected by him, because they are inoperative upon his sensorial nervous substance. Man probably is endowed with every *kind* of sensation possessed by animals, though each special sense may, in certain animals, be more highly developed. In the warm-blooded Vertebrata, the same senses undoubtedly exist as in Man, though modified in acuteness in different instances. In the cold-blooded Vertebrata, especially in Amphibia and Fishes, the low temperature of the body would seem incompatible with so high a grade of sensibility as exists in the warm-blooded species, unless, indeed, their nervous substance be differently endowed. The influence of a low temperature is probably more felt in regard to common sensibility, touch, taste, and smell, than in hearing and sight, which, so far as the structure of their recipient organs, the ear and the eye, will permit, may be very acute in these animals. Still lower in the animal series, as in the aquatic Mollusca, the similarity of temperature between the body and the external medium, and the simplification of the sensory apparatus, are doubtless associated with a further diminution of activity in the function of sensation. In the Molluscoida, special sensation is probably almost entirely replaced by common sensibility. In the Annulose animals, those in which the temperature is comparatively high, viz., the Insects, probably enjoy, not only greater special sensibility, particularly as regards sight, but also a more acute common sensibility than the colder aquatic Annulosa, such as the Crustacea and Annelida. In these animals, movements excited by external irritation by no means imply the acuteness of sensibility which is generally supposed. In the Annuloid animals, and also in the Cœlenterata, special sensibility can only be feebly manifested by those few species which possess simple ocular spots, and the so-called auditory sacs; whilst their common sensibility must be extremely feeble. In the Protozoa, sensibility to light, or the warmth which accompanies it, is noticeable in the Infusoria; but in regard to any other sensation there is no distinct evidence of its presence in these the lowest animals.

In conclusion, it may be added, that in no animal are actions or movements observed which require for their explanation the supposition of the existence of any additional sense; so that, not only are we unable, from the nature of things, to prove the existence of additional senses in animals, but their behavior does not justify the inference that such senses are present in them.

The utility of each sense is very greatly enhanced by the numerous *qualitative* sensations which we are enabled to experience through it; such, for example, as the almost endless distinctions of light and shadow, color and hue, force, pitch and timbre of sound, and the numerous varieties of odors and tastes. The qualities of sensation perceived through the same sense are, indeed, most diverse. The causes of the qualitative differences of color and of sound are closely related, being, in both, dependent on definite numerical relations between the numbers of the luminous or sonorous undulations; but, as regards smell and taste, no such relations have yet been established.

Pain.

When any of these external senses, or senses responding to external causes, are unduly excited by their proper stimuli highly intensified, *pain* is the result, as is shown by the effect of gazing at the sun, or at any other extremely vivid light, especially if long continued, and also by the effects of shrill, loud, and grating noises; but the pain, in each of these cases, is *peculiar*. That which is caused by acrid smells, very pungent tastes, the action of irritants on the naked cutis after blisters, the pressure of sharp points or heavy weights, and by bodies in rapid motion, in the organs of smell, taste, and touch, is due to excessive stimulation of the common sensibility. The occurrence of pain from the over-excitement of the special senses, indicates their relation to this common sensibility. It is said, however, that powerful *mechanical* stimulation of the optic nerve causes no pain, but intense luminous sensations; this is probably dependent on the still existing connection of the nerve with at least one eyeball. But it is the common sensibility which is ordinarily excited in the feeling of pain. Such pain is not merely an intensified normal sensation, for very hot bodies cause a painful, and not an exalted thermal sensation. The common sensibility is also actively concerned in those various sensations which inform us of the conditions of the nervous centres, produced, not by external stimuli, giving us a knowledge of external objects and forces, but by internal states of the organism; for these so-called *internal sensations*, some of which are pleasurable and some painful, seem to be distinct modifications of common sensation.

Internal or Corporeal Sensations.

These *internal sensations*, though dependent, as just stated, on conditions of the nervous system, are, like the external sensations, usually referred to special seats, that is, to certain tissues or organs of the body, and hence may be called *corporeal*. Some are referred to the organs of *animal* life, and others to the organs of *vegetative* life.

Of the former, the muscular sensations are the most important; the sensation of resistance within the joints, is also very evident. The internal sensations proper to the states of the nervous system, or the *nervous* internal sensations, are those of pain generally, especially of neuralgic pains, sensations of vertigo, torpor, drowsiness, mental fatigue, nervous exhaustion or shock, and irresistible tendency to sleep.

The *muscular* sensations are those of uncomfortableness, restlessness, muscular languor, faintness, lassitude, heaviness, fatigue, weariness, as shown in the heavy falling eyelids and bodily exhaustion which precede sleep, intermittent spasm and cramp, and the feelings of general health, buoyancy, bodily energy, and capacity for corporeal work. It is also by a similar class of sensations, which, less vague in their seat, are known under the collective name of the *muscular sense*, that we become conscious of the degree of effort made, or of the resistance met with and overcome, in regulating the amount of force employed in all the muscular movements of the body, such as lifting or moving weights, resisting external forces, balancing the body in walking, moving the arms in the performance of prehensile and manipulative acts, and exercising the organs of voice and speech. When this sense is lost in certain muscles, their actions can no longer be regulated, or even commanded, except through the agency of the sight (page 287). On board a ship in a rolling sea, the muscular sense is called into unusual activity to neutralize the effect of the motions of the vessel, which disturb the equilibrium of the body; on returning to land, the compensatory movements rendered necessary at sea, continue for a time.

To this sense, moreover, we owe our feeling of the stability of position of the body, in sitting or in standing; when it is wanting, vertigo or giddiness ensues, caused by a loss of the sense of equilibrium, and accompanied by staggering efforts at recovery of position, or by falling. Vertigo may be produced by rapid rotatory movements of the body, whether active or passive; also by the long maintenance of the horizontal posture, by various diseases, by injuries of the head, and by many medicinal agents. Though manifested by, and referred to, muscular actions, its real cause is some disturbance in the nervous centres, which govern and co-ordinate these movements.

Our notions of space and distance, are also derived, or deduced as inferences, from the exercise of the muscular sense, which enables us to determine the precise position of the body, when at rest, or in motion through space. The relative positions of external bodies, whether these be at rest or in motion, are also determined by reference to the fixed or movable state of our own bodies. If we are at rest, moving objects appear to us to move, and stationary ones to be fixed. But if, being at rest, we imagine ourselves, through a disturbance of the muscular sense, to be in motion, or if we perform irregular and erroneously estimated movements, then external objects seem to move accordingly; on the contrary, the movements of outward objects may, after a time, seem to depend on motion in our own bodies. In the former case, we refer a bodily condition of movement to the outer world; in the latter, movements in the outer world are referred to a supposed bodily condition. In this latter case, giddiness may be produced, even after the eyes are closed. This state, which is known as *secondary vertigo*, may be produced by steadfastly looking at quickly moving objects, by after-impressions caused by moving objects, by looking down from great heights, and by rapid unusual movements of the body. Rotatory movements will produce vertigo, even though the eyes be closed.

Lastly, to the muscular sense, combined with certain feelings of pressure and strain about the joints, seated probably in the ends of the bones which support the cartilages, and in the ligaments which tie the bones together, we are indebted for our notions of resistance and of weight; these, however, are not the results of a simple sensation, but of inferences drawn from the perception of the effects of gravity and force. The muscular sense appears to be keenly exalted in somnambulists, as well as the power of muscular combination and control. It has been suggested, that the special sensorial centre of this muscular sense is in the cerebellum (page 290). This, however, seems improbable, for when it is lost in any particular muscle or muscles, the common sensibility disappears with it; hence, it has been regarded as only a modification of this common sensibility.

The internal sensations dependent on states of the organs of *vegetative* life, are exceedingly varied, in accordance with the number and variety of those organs themselves. Many of them must be produced by impressions made on the ultimate ramifications of the sympathetic nerve, or of branches of the cerebro-spinal nerves which are associated with these in their distribution. They are chiefly referable either to the digestive organs, the organs of circulation, or the respiratory organs.

The internal sensations connected with the *digestive system*, are thirst, hunger, satiety, and nausea. *Thirst* is principally a local sensation, being chiefly referred to part of the tongue and palate; but it is evidently dependent upon a general state, for it may be distinguished from mere dryness of the mouth and fauces. This latter condition, which is produced by sleeping with the mouth open, is quickly relieved by shutting it, or, at most, by merely moistening the mouth with water, and immediately emptying that cavity. True thirst is not so relieved, but only by copious drinking, or by continual immersion of the body in water, even though this be salt. The general condition on which thirst immediately depends appears to be a deficiency of water in the blood; and as the blood is the source of all the secretions, these are everywhere diminished, and those of the fauces and mouth are necessarily deficient. An additional cause of dryness in the throat especially, is, that its surface is momentarily exposed to evaporation in the respiratory act, so that thirst is consequently localized in the fauces. The sense of dryness of those parts is communicated to the sensorium by impressions conveyed along the fifth, the glossopharyngeal, and the pneumogastric nerves, the two latter of which are probably more sensitive than other nerves to the condition of dryness. Not only the want of water in the blood produces this feeling, but the excess of saline matter will likewise cause it, as is noticed after taking much common salt with the food, drinking salt water, or even taking draughts of neutral vegetable salts, such as seidlitz powders. It is also produced by hot condiments, and by strong alcoholic beverages. It is particularly and distressingly noticeable in cases of hemorrhage after gunshot wounds or other extensive injuries, and in all cases of fever. The intense thirst experienced by shipwrecked sailors, and by criminals subjected to the torture of thirst, is accompanied by burning pains and sufferings, more difficult to bear even than those induced by prolonged starvation, and ending in delirium and mania. Thirst is more immediately and successfully quenched by water than by any other fluid. It is water which the system absorbs from the blood, in thirst, the tissues, as well as the secretions, requiring it; and the introduction or imbibition of this fluid is the natural remedy for this sensation.

The sensations of *appetite* and *hunger*, the former of which is pleasant, and the latter painful, are by some regarded as chiefly muscular sensations. They are referred to the stomach, in the same way as thirst is referred to the mouth; but, like the latter sensation, they would seem to depend on a general condition of the system, and perhaps essentially on some state of the blood. The muscles of mastication are said to participate in the sensation of appetite; and a flow of saliva is excited by it. It may be supposed that the nerves of the stomach convey the sensations proper to that state of the system induced by fasting, more readily than the nerves of any other part of the body. Several theories have been suggested to explain the gnawing feeling of hunger, which is even more decidedly felt in the stomach than appetite. Some physiologists, offering a mechanical explanation, have thought that it is owing to the rubbing together of the sides of the empty stomach; but this explanation is opposed to the facts, that the stomach may be empty without hunger being felt, and that, in the fasting condition, when hunger is experienced, the walls of the stomach are quiescent. As a chemical theory of the cause of hunger, it has been suggested, that it depends on irritation excited by unused gastric juice; but no gastric juice is secreted during fasting. A physiological explanation consists in supposing that the feeling of hunger is owing to a turgescence of the bloodvessels of the mucous membrane of the stomach; but this membrane is pale when the stomach is empty; indeed, the secretion of gastric juice takes place rapidly, and the membrane then suddenly becomes red. That the sensation of hunger depends partly on some condition of the stomach itself, is shown by the fact, that it may be allayed by the introduction into that cavity of almost, or perfectly indigestible substances, such as sawdust, or clay; even when the stomach is filled with digestible substances, the feeling of hunger is relieved before any material quantity of digested food can have been absorbed. Hunger is not, however, so speedily relieved as thirst. On the other hand, that it depends mainly on a peculiar condition of the system, is shown by the experiments of injecting nutrient substances, in the form of enemata, or into the blood itself, either of which is followed by a cessation of the feeling of hunger. The nerves distributed to the stomach, which are concerned in this sensation, must either be derived from the pneumogastric, or from the sympathetic nerve; but the latter, it must be remembered, contains fibres derived from the cerebro-spinal system. It has been shown that the sense of hunger, as manifested by the desire of animals for food, is not permanently destroyed, but merely diminished, after division of the pneumogastric nerves (Reid and Bernard); but whether the persistence of hunger is owing to the subsequent reunion of those nerves, or to the action of the still uninjured sympathetic branches, is not known. The sensation of *satiety* is said to persist in animals, as evidenced by their conduct, even after division of the pneumogastric nerves; but the experiments on this point are not satisfactory. The final cause of the sensation of hunger, not only in animals, but in man, is to impel them to seek for the food absolutely necessary to sustain life; and indirectly, hunger may be said to stimulate men, in an uncivilized state, to the chase, or to mutual conflict, and, in civilized society, to the exercise of their intellect and bodies in industrial and other occupations.

The progress from fasting to *starvation*, is at first accompanied by an exaggeration of the sensation of hunger to a ravenous craving after food; but after a time, if unsatisfied, this sensation passes off, a condition of indifference to food supervenes, and no further sensation of appetite is experienced, extreme prostration and diminution of sensibility setting in, and ending in delirium and death.

Another sensation, chiefly referred to the stomach, is that of *nausea*, which, however, is often accompanied by distressing sensations about the pharynx and palate, and by general sensations of depression, sinking at the precordia or pit of the stomach, and a lowering of the heart's action. It is said to be a muscular sensation (Weber), though formerly it was regarded as a modified gustatory sensation. It may be produced in many ways, as, by irritation of the stomach, indigestion, improper quality or quantity of the food or drink, or by emetic medicines introduced either into the stomach, or the lower part of the alimentary canal, or injected beneath the skin, so that they can be absorbed into the blood, or even by the injection of such substances directly into the bloodvessels. Nausea may also be induced through the nervous system, as a reflex phenomenon, by tickling the fauces, or by the inhalation of chloroform (through its action on the brain), by odors or tastes, by the motion of vessels at sea, by severe pain, by concussion or diseases of the brain, by conditions of the blood in the early stages of fever, by the sympathetic effect of various diseases, by general shock from severe injuries, especially from blows over the great solar plexus, and even by mental causes. It is certain, therefore, that this sensation of nausea, or sickness, though referred to the stomach, must depend, sometimes, at least, upon general conditions of the system. The movement excited by the condition of nausea or sickness, named *vomiting*, will be mentioned after the description of the movements of the stomach, in the Section on Digestion.

The internal sensations associated with the *circulating system*, are fewer than those connected with the digestive organs, at least in a state of health, in which not even the powerful and incessant action of the heart is perceived by the mind. Were it otherwise, the amount of attention given by the mind to such internal sensations, would occupy it, so as to interfere with its perception of external phenomena. In weak conditions of health, in sudden excitement, and in certain diseases, however, the sensation of *palpitation of the heart* is not uncommon. The sensation of *fluttering* at the pit of the stomach is usually not cardiac, but either diaphragmatic or gastric. *Heartburn* is also erroneously named; for it is a gastric sensation, dependent on the accumulation of acid, or other acrid fluid in the stomach. In morbid conditions, actual pain is felt in the heart; and, in mental states, a sense of weariness is referred to that region. Morbid sensations of heat or chilliness along the veins, or in the blood, as such feelings are termed, are probably owing to conditions, not of the vessels or blood, but of the nerves of common sensation, especially of those of the skin.

Of the internal sensations connected with the *respiratory organs*, by far the most powerful is that known under the name of the feeling of *want of breath.* It is this which creates an irresistible desire to inhale air, and an uncontrollable involuntary effort to inspire. Its final cause is undoubtedly to maintain life, which is so immediately dependent upon the continuance of the respiratory function. It is difficult to determine the precise seat to which this sensation is referred; but it is chiefly located in the larynx and neighboring parts of the throat, and also in the anterior part of the chest and precordia, opposite the level of the diaphragm; it is probably, in great part, a muscular sensation. Its cause is, however, general, and perhaps depends on the presence of an undue quantity of carbonic acid in the blood, which, reaching the nervous centres concerned in receiving impressions from the respiratory organs, and in governing the respiratory movements, at once excites the sensation of distress, and the involuntary impulse to inspire, which is best calculated to relieve it. The sensation of want of breath is named *apnœa.* Difficulty of breathing is named *dyspnœa*, an embarrassing sensation also referred to the larynx, throat, and chest. These conditions may be produced by diminution in the number and depth of the respirations, by breathing a vitiated atmosphere, by obstacles to the introduction of fresh air into the lungs, as in asthma and œdema of the larynx, by diminution of the respiratory surface, as the result of disease, and by defective action of the blood as a conveyer of oxygen.

With regard to the muscular sensations of the contractile organs employed in the functions of digestion, circulation, and respiration, it is remarkable that the *respiratory muscles*, although they are identical in structure with the rest of the voluntary muscles, and are themselves subject to the will, and, though they are constantly in action during the whole of life, yet do not habitually, and in healthy conditions, convey the sense of fatigue to the mind. As regards the *heart*, no direct sense of fatigue in its muscular walls is experienced. So, also, the movements of the stomach and intestines are usually unperceived. In inflammation of any of the parts just considered, as of the intercostal muscles, the diaphragm, the heart, and the alimentary canal, acute pain, spasm, or cramp, is not uncommon.

The organs of vegetative life are, it would seem, in health, possessed of little or no sensibility; but when irritated, inflamed, or organically diseased, they become more or less acutely sensitive; just as the common sensibility, and even the special sensibility, manifested by the organs of animal life, may, when unduly exalted, give rise to pain. Pain is a necessary consequence of sensibility; and almost every tissue or organ, when inflamed, gives rise to a peculiar pain. Painful sensations, however, are frequently not precise. They are often erroneously localized, especially in cases of diseases of parts not ordinarily sensitive. The radiation of severe pains is a familiar fact, and the irradiated pains are often more severe than those in the seat of the primary irritation; for the latter may even cease from exhaustion of the nerves. Pain also renders nerves incapable of reaction under normal stimuli.

Pain is as old in the world as the existence of a sensory nervous apparatus. The gift of sensibility is necessarily accompanied by a liability to pain. The tension of the nervous energy connected with feeling is, as it were, adapted to certain ranges of strength in the stimuli which excite sensation; and such an adaptation necessarily implies that when the limits of agreeable stimulation are exceeded, pain is the result. According to this view, pain is a necessary evil under the existing relations between the nervous system and external agencies. But, happily, pain itself cannot be conceived by the imagination, nor recalled by any effort of the memory, and is, for the most part, transitory. Considered teleologically, pain has a beneficent action, surpassing that of pleasure, which may, through uncontrolled appetite and desire, lead to the undue use,—that is, to the abuse,—of the various functions. Pain, moreover, is conservative, suggesting the necessity for moderation and caution in the exercise of the functions both of animal and vegetative life. Pain also is preservative, creating a feeling of alarm and a sense of danger by exciting through nervous sympathy, or through the blood, other organs or distant parts of the system. Thus pain in a single part excites general febrile disturbance, and so the whole system may be said to take warning. Pain also forms a chief consideration in the symptomatology and diagnosis of disease, which may thus be detected and combated in time to save life. The importance of pain in morbid processes is recognized in the term *dis-ease*, the obvious etymology of which is, as we ordinarily pronounce the word, forgotten. Pain is, moreover, the cause of wide sympathies between individual persons; fellow-suffering excites human charity and beneficence. It is to be noted that, in the ordinary act of dying, the sensitive portion of our frame, or the sensorium, dies before the merely motor apparatus, with its excito-motor or non-sensitive nervous centres; and thus the senses are subdued, and, as it were, annihilated, sometimes long before the last breath is drawn. Finally, it may be not unworthy of note that whilst limited suffering is the inevitable lot of sensitive animals, the relief of that suffering by narcotic and anæsthetic agents, such as henbane, opium, ether, or chloroform, ordinarily necessitates the co-operation of substances derived directly or indirectly from the vegetable kingdom.

THE SENSE OF TOUCH.

The Organ of Touch.

The skin is the principal part of the body concerned in the sense of touch, but the tongue and lips also possess this sense. The nails and hairs are appendages of the skin, and often minister to the sense of touch. The skin is further provided with sebaceous and sudoriferous glands. It constitutes a protecting covering to the whole body, and is known as the *common integument.*

The skin consists of an external or superficial layer, destitute of bloodvessels and nerves, named the *cuticle*, Fig. 66, 1, 2; and of an internal or deeper layer, abundantly supplied with nerves, and highly vascular, known as the *cutis vera* or *true skin*, 3. These two layers, though separable, are closely adherent.

The skin is thicker on the back than on the front of the body, thicker on the outer than on the inner surface of the limbs, thicker still in the palms of the hands—but thickest of all in the soles of the feet. It is very thin on the eyelids, in the tube of the ear, and on the red borders of the lips, where it becomes continuous with the mucous membrane of the mouth. The surface of the skin is marked with fine intersecting lines or furrows, which divide it into minute angular spaces; these are large opposite the foldings of the joints. On the soles and palms, and especially on the toes and fingers, the skin is elevated into little ridges, usually parallel to one another, which sweep over the surface in curved lines, Fig. 65; they correspond with rows of the vascular eminences belonging to the true skin, named the papillæ.

Fig. 65.

Fig. 65. Portion of the skin from the end of the thumb, slightly magnified, showing the curved ridges and intermediate furrows. Upon the ridges are seen the orifices of the ducts of the sweat glands.

The *cuticle*, also called the *epidermis* (επι, upon, and δερμα, the skin), is made up of superimposed layers of nucleated epidermoid cells. (See p. 65, Fig. 43.) The superficial cells, Figs. 66, 67, 1, are flattened, dry, and transparent, and firmly held together, assuming at the surface, the form of thin, coherent, horny scales; the cells in the deeper layers, 2, 2, resting on the cutis, are soft, roundish, or compressed, and easily separated from each other; this deeper layer is known as the *rete mucosum of Malpighi*, or, sometimes, as the *Malpighian layer*, or the *mucous layer.* The color of the skin in the dark races, is due to the presence of pigment, chiefly found in the form of colored granules, usually situated in certain of the epidermoid cells. These granules are fewer near the surface of the cuticle, where the flattened scales are paler. The color of the skin is, therefore, chiefly seated in the rete mucosum of the cuticle; the true skin, in the dark races of men, has the same color as that of the European.

It is the non-vascular cuticle which, owing to the exudation of a fluid between it and the vascular cutis, forms the blebs or bullæ seen in certain skin diseases, and after burns, scalds, or the application of blisters. On separating the cuticle from the cutis, after death, when some decomposition has taken place, the under surface of the former is found to be accurately moulded to the upper surface of the cutis, closely following all the flexures, markings, and ridges of the skin, which are really formed in the cutis; it further presents numerous small pits or depressions, which receive the conical projections of the cutaneous papillæ. A prolongation of the cuticle lines the sides of the hair follicles, and the glands of the skin.

In the palms and soles, where the entire skin is thickest, the cuticle measures about $\frac{1}{12}$th of an inch; in other parts, where the skin is very thin, it is not more than $\frac{1}{240}$th of an inch in thickness. In the palms and soles, it grows thicker, from the effects of hard work and pressure. The greater thickness of the whole skin, in some situations, as in the hands and feet, cannot, however, be solely attributed to the effects of external influences, for the skin of these parts is thickest, even in the new-born infant. During life, the cuticle is constantly

Fig. 66.

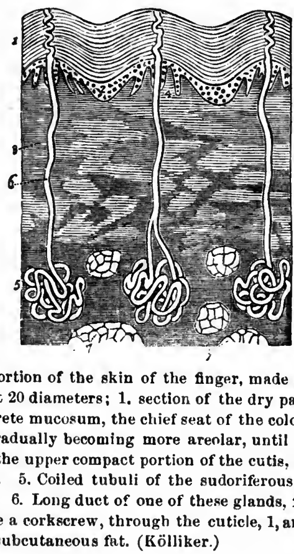


Fig. 66. Vertical section of a portion of the skin of the finger, made across three of the curved ridges, shown in Fig. 65, magnified about 20 diameters; 1. section of the dry part of the epidermis. 2. Section of the soft, mucous, or Malpighian rete mucosum, the chief seat of the coloring matter in the dark races. 3. Section of the cutis or derma, gradually becoming more areolar, until it joins the subcutaneous areolar adipose tissue. 4. Elevations of the upper compact portion of the cutis, named the papillæ, placed in rows across the ridges just mentioned. 5. Coiled tubuli of the sudoriferous, or sweat glands, lying near or in the areolar subcutaneous tissue. 6. Long duct of one of these glands, forming a waved line through the cutis, 3, but passing spirally, like a corkscrew, through the cuticle, 1, and then opening on the surface of a ridge. 7. Small masses of the subcutaneous fat. (Kölliker.)

undergoing loss, by the process known as desquamation, which consists of a throwing off of the superficial epidermoid scales. But these are constantly being renewed by fresh epidermoid cells, originating on the surface of the true skin, and gradually undergoing transformation, from the spherical to the flattened shape, as they approach the surface of the cuticle.

The *cutis*, or *true skin*, also called the *corium* and *derma*, Figs. 66, 67, 3, covered everywhere by the cuticle, is a dense, moist, tough, and flexible fibro-areolar membrane, of a pinkish-white color. It is adherent to the subjacent parts generally, becoming blended with the subcutaneous areolar and fatty tissue, the fasciæ, and even with the cutaneous muscles.

The cutis is made up of interlacing bundles of white areolar tissue, mixed with yellow elastic fibres. Immediately beneath the rete mucosum, its structure is almost homogeneous, presenting a compact, scarcely fibrillated appearance. Somewhat deeper, bundles of fine fibres, with small areolæ, appear. In the deepest layers, the fibres are large and coarse; the dense areolar network is here loose, and opening out, incloses the hair follicles with their sebaceous glands, and small masses of fat. In most situations, scattered contractile fibre-cells, or plain muscular fibres are found, mixed up with the fibrous and elastic tissues; they are always present where hairs exist, to which parts they are often attached; on the palms and soles, where these are absent, no muscular fibres are ever seen. The cutis, in some parts of the body, as in the palms and soles, is closely adherent to the fascia beneath it; in the face, it gives attachment, by its under surface, to many of the fibres of the muscles of the eyebrows and mouth. The skin is very loosely attached over the angles of the joints, where, moreover, the so-called *subcutaneous bursæ* are found; these are closed sacs, situated between the integument and the prominences of the bones, by means of which the movements of the parts are facilitated. The thickness of the cutis varies in different parts of the body; it is thickest in the sole, and thinnest in the eyelids, being, in the former situation, about a line and a half thick, and in the latter, less than a quarter of a line; as a rule, it is thicker in the male than in the female. The thickness of the entire skin is determined by the cutis, except in the palms and soles, where the cuticle is disproportionately thick.

The surface of the cutis, as seen when it is denuded, is covered, in many places, with little conical-shaped projections, called *papillæ*, Fig. 66, 4. These are prolongations of the upper compact tissue of the cutis into the rete mucosum of the cuticle, from the depressions in which, already mentioned, they can be drawn out, in macerated specimens, after death. The papillæ are best seen on the palms of the hand, where they are largest and most numerous; they are usually arranged in double rows upon the cutaneous ridges (Figs. 65, 66), and are generally divided, so as to form compound papillæ, 67, *a*. In the palm, the number of *simple* papillæ on a Paris square line ranges from 150 to 200; upwards of 80 *compound* papillæ have been counted on the same space. (E. Weber.) On the free border of the lips they are also very numerous, but they do not present any regular arrangement. The cutaneous papillæ on the fingers and palm measure from $\frac{1}{100}$th to $\frac{1}{200}$th of an inch in length; in the soles, they are nearly as large, but in other situations, where there is less tactile sensibility, they are few in number, short, small, and scattered, measuring from $\frac{1}{500}$th to $\frac{1}{1500}$th of an inch in length; on some parts of the body, the papillæ become indistinct, or are even altogether absent.

The cutis is abundantly supplied with bloodvessels, lymphatics, and nerves. Its general surface is covered with a close capillary network, from which fine looped vessels project and enter the papillæ, Fig. 67, 5. The lymphatics also form a close network on the surface. The nerves pass upwards from the subcutaneous cellular tissue, and form, as they approach the surface, minute plexuses, from which nerve-fibres are given off. Some of these fibres are lost in the compact tissue of the cutis; others end, perhaps, in loops; whilst, lastly, many of them pass into certain of the papillæ only, for it is said that some of these do not receive nerve-fibres. In the papillæ, the fibres end in loops,

Fig. 67.

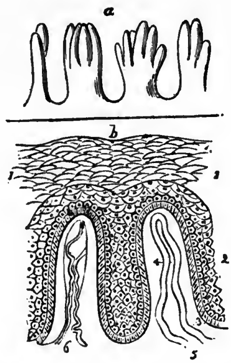


Fig. 67. *a*, a larger view of the cutaneous papillæ, showing the secondary papillæ into which they are often divided. Magnified about 60 diameters. *b*, still larger diagrammatic view of two simple cutaneous papillæ, with their epidermic covering. 1, dry scaly part of epidermis. 2, soft part, or rete mucosum, consisting of compressed cells. 3, cutis, or true skin. 4, papilla. 5, vascular capillary loop in one papilla. 6, tactile corpuscle, with two nerve-fibres winding up, and becoming lost upon it. (Kölliker.)

or, as in the fingers, the sole of the foot, and, according to Kölliker, on the red margin of the lip and the point of the tongue, they appear to terminate on, or in, small oval condensed bodies, called *tactile corpuscles* or *axile bodies*, Fig. 67, 6 (Wagner), situated in the centre of the papillæ; or they become lost in the central part of those papillæ which are unprovided with distinct tactile corpuscles. In any case, it has been supposed that the nerve-fibre turns back to rejoin some nerve-cell in the nervous centres. (Beale.) The tactile corpuscle fills up the greater portion of the papilla, and according to some is surrounded by the ends of the nerves; by Gerlach, it is also said to be perforated by them. According to Wagner, these bodies have altogether a special structure; but, by Kölliker, they are said to consist of condensed homogeneous connective tissue, covered by imperfectly developed elastic fibres, resembling the interlacing bundles of areolar tissue and elastic fibres of the true skin. Huxley considers the axile bodies to be formed by the continuation of the neurilemma or sheath of the nerve, which is much developed in this situation. In the conjunctiva, lips, and other parts, the axile body sometimes presents a knob-like form, and consists of a fine nucleated sheath, containing a granular plasma, within which the axis-cylinder of the nerve ends in a simple blunt point. (Krause.) Their number varies in different parts; on the palmar surface of the distal phalanx of the index finger, there are about 108 on a square line, on the second phalanx 40, on the first 15; on the palmar surface of the metacarpal bone of the little finger and on the middle of the sole of the foot 8, and on the tip of the great toe 14.

The cutaneous papillæ are vascular organs, serving to increase the nutrient and formative surface for the generation of the constantly wasting epidermis; whilst those which contain nerves, are the proper organs of touch, their number, size, and complex development, being in exact proportion to the perfection of this sense in different parts of the skin. Two kinds of papillæ have been described by Wagner, viz., one containing capillary loops only, and the other being merely provided with nerve-fibres and axile bodies; but, according to Kölliker, the vascular papillæ of the lip contain nerves, and the papillæ of the palm of the hand, which possess axile bodies, frequently contain capillary loops.

In certain situations in the subcutaneous tissue, as in the hands and feet, some of the cutaneous nerve-fibres pass into curious little oval bodies, varying from $\frac{1}{15}$th to $\frac{1}{10}$th of an inch in length, named the *Pacinian corpuscles.* These consist of numerous concentric membranous laminæ, composed of spirally arranged fibres, and having between them, spaces filled with fluid. In the centre, is an elongated chamber, into which the axial part of the nerve fibre penetrates, and which also contains a semi-fluid substance. The nerve fibre enters these bodies at a sort of pedicle, together sometimes with a capillary loop; and then, losing its medullary sheath, becomes reduced to its axis-cylinder, and penetrating to the internal chamber, ends in a little bifid or trifid knob, perhaps turning back again. Similar bodies are likewise found on the sympathetic plexuses of the abdomen, in man. In many animals, these corpuscles are found in large numbers in the feet; they are very abundant in the skin, feet, bill, and tongue of birds. They are especially well seen on the mesenteric nerves of the cat.

The *nails* are modified parts of the cuticle, with which they are continuous along the hinder part of their edges, by their upper surface near the root, and by their under surface near the tip; hence, when loosened by decomposition, they slip off from the true skin, in intimate connection with the glove-like cuticle. They consist of a deep soft layer, Fig. 68, 2, composed of roundish, somewhat compressed, epidermoid cells and of a hard superficial stratum, 1, made up of flattened, horny, and intimately adherent cells. The under concave surface of the nails, is accurately moulded on to the cutis or true skin, to which it is firmly adherent during life. The part of the cutis beneath the nail, is called the *matrix*, or *bed*, 5; posteriorly, it is doubled on itself, forming a semilunar *groove*, Fig. 68, *b*, or recess, into which the hinder edge or so-called *root* of the nail is closely set. The matrix is highly vascular; it is covered with numerous vascular papillæ, Fig. 68, *a*, 5, running lengthwise under the nail; but opposite the crescentic white spot seen near the root of the nail, called the *lunula*, the papillæ are smaller, less vascular, and irregularly scattered.

The nails, like all epidermoid tissues, are constantly being reproduced, growing in length by continual additions of new cells to their posterior margins, and in thickness by like additions to their under surface. When a nail is torn out, or thrown off, in consequence of disease, a new and perfect nail is formed, provided the matrix is uninjured.

Fig. 68.

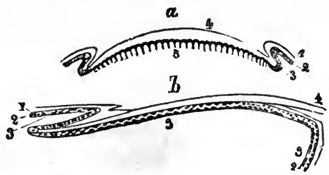


Fig. 68. *a*, transverse section of the nail, and its matrix. *b*, longitudinal section of the same: both figures are diagrammatic. 1, the outer cuticular layer. 2, the rete Malpighianum, or mucous layer, of the cuticle. 3, the cutis. 4, the nail substance. 5, the ridges of the cutis, of which the matrix or bed of the nail consists. (Kölliker.)

The *hairs*, like the nails, are non-vascular and insensible outgrowths of the cuticle, springing from a minute sunken point of the surface of the true skin, which has there no other cuticular covering. They are found on all parts of the body, excepting the palms of the hands, the soles of the feet, the backs of the last phalanges of the fingers and toes, and the surface of the upper eyelids; they present great varieties in length, thickness, and color, in the male and female, at different ages, and in the various races of mankind. With the exception of the eyelashes, which are set perpendicularly to the surface, they are usually inserted obliquely into the skin. The soft swollen end of the hair, which is embedded in the skin, is called its *root* or *bulb*, Fig. 69, *a*, 5; the part which projects above the surface, is called the stem or *shaft*, and the terminal extremity, the *point*. The shaft is usually cylindrical in shape, but is often somewhat flattened, or even grooved. It consists of an outer part, called the *cortex*, Fig. 69, *a*, *b*, *c*, composed of a single layer of adherent and imbricated scales, the edges of which, directed towards the point, form fine wavy transverse lines; beneath the cortex, is the so-called *fibrous* part of the hair, which constitutes its bulk, and consists of fusiform cells clustered into flattened fibres, which run longitudinally, and are intermixed with pigment granules; lastly, the very deepest cells, occupying the centre of the shaft, and constituting the *pith* or *medulla*, are not elongated into fibres, but are somewhat polyhedral, and loosely connected together, containing chiefly pigment or fat granules. The pith is only found in certain hairs, and does not extend so far as the point.

The minute depression from which a hair emerges, is called the *hair follicle*, or hair sac, *a*, *b*, 6. This, which varies from one to three lines in length, is buried in the true skin, or, as in the case of the larger hairs, reaches even into the subcutaneous fat: it receives, in nearly all cases, the ducts of two sebaceous glands, *a*, 4. The sides of the hair follicles are firm, and consist of two layers, an outer soft, fibrous, and vascular, and an inner non-vascular homogeneous layer, both being prolongations from the cutis; each follicle is lined by extensions of the horny and soft layers of the cuticle, 1, 2, forming the part called the *root-sheath*, the inner stratum of which adheres closely to the hair. At the bottom of the follicle, is a more or less elevated portion of the cutis, often forming a distinct *papilla*, 7, which is destitute of cuticle, being covered, instead, by the attached extremity of the hair, which, indeed, is formed on the papilla. The root of the hair is composed of soft, pale, and somewhat compressed, nucleated cells; it is intimately adherent to the root-sheath or cuticular lining of the follicle; when a

Fig. 69.

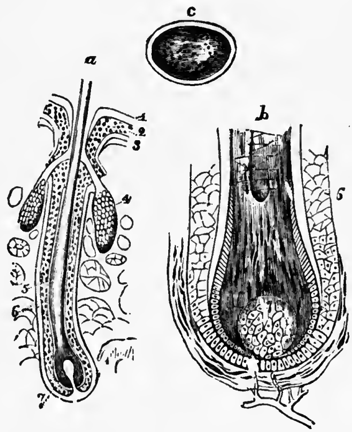


Fig. 69. Diagrams of the structure of the hair, hair follicle or sac, and sebaceous glands (Kölliker). *a*, root of a hair, in its follicle. 1, outer, dry layer of cuticle. 2, Malpighian or mucous layer, both dipping into the hair sac. 3, cutis, or true skin. 4, sebaceous glands. opening into hair sac. 5, root of hair. 6, walls of hair sac. 7, papilla, on which the hair grows. *b*, larger view of lower end of root of hair, and bottom of hair sac. 6, the hair sac, showing the outer and inner root sheath, the latter adhering to the hair. 7, the vascular papilla on which the hair grows. The hair itself shows its fibrous structure, its dark medulla, and the transverse lines of its scaly covering. *c*, transverse section of a hair, showing its outer covering, its fibrous part, and the central softer medulla or pith. (After Kölliker.)

hair is plucked out, it comes away with this cuticular lining, which clings closely round its root; the vascular papilla at the bottom of the follicle, however, remains, and a new hair is generated upon it. If the papilla be destroyed by injury or disease, no new hair is formed. The papillæ resemble those on the surface of the true skin, being highly vascular; all, except the papillæ of the finest hairs of the body, probably receive nervous fibrils; for pain is produced when a hair is pulled at, or plucked out. The papillæ situated at the roots of the large whiskers, or *vibrissæ* of the cat, seal, and other animals, which are used as feelers, are supplied with very large nerves. The hairs themselves are destitute of nerves.

It is on the papillæ that the hairs are formed by the production and metamorphosis of a succession of nucleated cells, as in the case of the nails and epidermis. These cells undergo alterations for some distance along the stem of the hair, which so becomes narrower than the root or bulb. The softer central portion, whether deserving the name of the pith or not, though of course non-vascular, is probably permeable to nutrient fluids, which nourish the hair. It is supposed that the sudden whitening of the hair from grief, fear, or intense mental excitement, is due to certain changes in the pith, produced through the blood.

Many of the unstriped muscular fibres, which, as before stated, are found in the substance of the true skin, pass obliquely down from the surface of the cutis, to the under side of the slanting hair follicles. It is the contraction of these fibres, which erects the hairs, by causing them to assume a vertical direction, and which, by drawing the follicles to the surface, and pulling in a little point of the skin, produces that roughness of the integument, generally called *horripilation*, goose's skin, or *cutis anserina.* The standing on end of the hair of the head, as the result of extreme fright, may be partly due to the contraction of such fibres, but it must also be dependent on the action of the occipito-frontalis muscle.

The *sebaceous* or *fat-forming* glands, Fig. 69, *a*, 4, from *sebum*, fat, are situated in the cutis, and exist in great numbers associated with the hairs, there being usually two for each hair follicle. Those of the larger hair follicles average about $\frac{1}{50}$th of an inch in width. They are proper appendages of the hair follicles, and are not found in the palms and soles, where no hairs exist. Each gland is a flask-shaped body, composed of from five to twenty little sacs, clustered around and leading into a common duct, which almost always opens into a hair follicle, each follicle receiving one or more ducts; sometimes, however, the ducts of the glands open upon the cutaneous suface. These glands are lined throughout by a fine epithelium, and their unctuous secretion first anoints the hair bulb, and then oozes out upon the stem and the neighboring surface of the cuticle, which it prevents from getting dry and cracked. On the nose and face the sebaceous glands are of considerable size. The Meibomian glands in the eyelids are large sebaceous glands.

The *sudoriferous* glands or sweat glands, Fig. 66, 5, will be described in the Section on Excretion.

Touch.

The modification of the sensory power by which the shape, size, solidity and other mechanical properties or qualities of objects are distinguished, constitutes the sense of *touch* or *tact*, or the *tactile sense.* The *sense of temperature* is also usually referred to this sense; and so likewise are the feelings of pain or its opposite. So far as is yet known the peripheral sensory organs and the nerve-fibres concerned in all these forms of sensation are the same. But, as already mentioned (p. 271), different paths in the spinal cord are supposed to be pursued by tactile, thermal, and painful impressions; and instances are recorded in which the sense of touch was lost, whilst that of temperature remained. As to the exact sensorial centres excited in each case, nothing is positively determined.

The simplest impression conveyed to the mind by the tactile sense is, as its name implies, that of *contact* with some external object, or the *touching of matter.* By the aid of touch, combined with *pressure*, or movement, or with both, we arrive, however, at more important results, viz., at compound impressions. For example, from touch and pressure we obtain the feeling of external *resistance;* and, according to the degree of this we acquire a knowledge of the solidity, viscosity, fluidity or aeriform conditions of matter, and thus gain our notions of hardness, softness, elasticity, impenetrability, and so forth. By touch combined with movement we successively arrive at the notions of measure and size, distance and space. By the same means we examine and appreciate the *forms* of bodies; and by the combined operation of touch, pressure, and movement, we learn the *characters* of *surfaces*, such as roughness, smoothness, or polish. Finally, by touch co-operating with the muscular sense or the feeling of *internal resistance*, we are able to appreciate weight. Touch, though the simplest and least special, is the most general, and, at the same time, the most direct, positive, and certain of the senses. It is the logical as well as the physiological parent of the other senses, which are, in the last analysis, modifications of touch. It is the sense the least liable to be deceived.

The sensations of contact and resistance, and also, it may be added, those of temperature, and of pain or its opposite, are always referred to the parts of the body acted on by the external object; in all cases, but especially in the first three, a certain perception of the regions touched, resisted, or heated, that is, of the *locality* or *seat of the sensory impressions*, is superadded; although, as we know, the actual seat of all sensations is in the part of the great nervous centres, named the sensorium. It is on the more perfect possession of this perception of the locality of impressions of contact, that the specialized form of sensation, which constitutes tact or the tactile sense, to a large extent depends.

All parts of the skin and the adjoining mucous membranes are endowed with the sense of contact or touch; but, in man, it is the hand, which, by common usage and cultivation, is the special organ of the higher tactile sense. It is most admirably fitted for its office, by reason of the number, size, arrangement, structure, and abundant nervous supply of its papillæ. The whole mechanism of the upper limb is, indeed, wonderfully adapted for the due fulfilment, not only of the prehensile, but also of the tactile functions of its digital extremities. The numerous articulations of the fingers, the length of the phalanges, the size and strength of the thumb, the power of bringing it into exact opposition with the ends of the fingers, so as to form, with them, as it were, a pair of pincers, enable the hand to span objects in all directions, and to examine their relative consistence, size, and character of surface. The bones and nails serve as firm points of support for the skin, and aid materially in the exercise of the tactile sense, and in its secondary or derived uses.

Those cutaneous papillæ which contain nerves, are the proper organs of tactile sensibility, their number, size, arrangement, complexity of structure, and nervous supply being, as exemplified in the hands and feet, in exact proportion to the perfection of this sense in different parts of the skin. The points of these papillæ (see Fig. 67, *b*) are situated nearer to the surface of the skin than the general surface of the cutis from which they project; and the cuticle upon them receives the pressure of external objects, and transmits it to the papillæ and their nerves. The tactile corpuscles and the Pacinian bodies are not *essential* to the exercise of touch; but they exist only in those situations in which this sense is most delicate or acute. The tactile corpuscles, far more numerous, and situated so much more superficially than the Pacinian bodies, the former lying in the papillæ of the cutis, and the latter being entirely subcutaneous, may act mechanically by supporting the expansions of the ends of the tactile nerves, so as to prevent their yielding to objects of touch. Thus, although not essential to sensation, they may serve to intensify the tactile sensibility of a part. The use of the Pacinian corpuscles is quite unknown. Their analogy to the electrical organs of certain fishes has not escaped attention.

The delicacy of touch has been estimated numerically, by measuring the power possessed by different parts of the surface, of distinguishing the double impression produced by the simultaneous application of the two points of a pair of compasses. (Weber.) It presents marked differences in different situations; it is greatest at the tip of the tongue and the end of the third finger. It was found, by Weber, that if the eyes be closed, and the points of a pair of compasses, protected by cork, be applied to either of the parts just named, the double impression is distinctly perceived when the points are approximated to within half a line of each other; for the perception of the double impression on the palmar surface of the last phalanges of the thumb and fingers, the points of the compasses must be separated one line; on the red surface of the lip, two lines; on the middle of the dorsum of the tongue, four lines: on the lower part of the forehead, ten lines; on the sternum, twenty lines; lastly, on the middle of the forearm, on the middle of the thigh, and over the middle of the cervical and dorsal vertebræ, the two impressions are not perceived, unless the points of the compasses are at a distance of thirty lines from each other; these last are the portions of the cutaneous surface in which the sense of touch is least perfect. The sensibility of the trunk is said to be greater in the middle line in front and behind, than at the sides.

It will thus be seen that the delicacy of touch in the most sensitive parts, is about sixty times greater than it is in the least sensitive parts; it presents, however, considerable differences in different individuals. It has been shown by Valentin, that some persons can distinguish the double impression at one-third of the distance at which it can be felt by others. The smallest distance at which the two points of the compasses can be distinguished, is called the limit of confusion. (Graves.) The two impressions of the points of the compasses are more plainly perceived when these are placed in a direction transversely to the trunk or limbs, than when they are applied in a longitudinal direction; but it is said that at the point of the tongue and the tips of the fingers, the two impressions are more easily felt when the points are applied in the longitudinal direction. The two points can, moreover, be distinguished at much shorter distances when they are applied consecutively, than when they are made to touch simultaneously. (Czermak.)

Accompanying the double sensation of the two points, is a distinct feeling of interspace between them; and if the points of the compasses be drawn, with a certain rapidity, over a tract of skin, they always appear to the mind of the person experimented upon, to be further apart, as they pass over regions possessing a relatively greater sensibility or sense of space. When the compasses are drawn in the opposite direction, the points seem to approach each other. Not only, therefore, are the points felt distinct at shorter distances in the more sensitive parts, but they seem to be more distant; this distance also seems greater when they are applied consecutively and not simultaneously. At a certain short distance the feeling of interspace disappears, but gives way to the sensation of an elongated body, and finally to that of a single point. If one point be cold and the other warm, they are felt, even at short distances, as double, although their relative position cannot be recognized.

The thinness of the epidermis, under certain circumstances, favors the acuteness of the tactile sense, as is shown in the comparison between the outer and inner aspects of a limb; but the delicacy of touch in the fingers is proverbial, although their epidermis is very thick. Touching or irritating the naked cutis causes pain, not a tactile sensation.

It is most probable that the delicacy of touch, and the power of discriminating distance, are proportional to the number of nerve-fibres supplying the skin, and indirectly, therefore, to the number of papillæ. If two impressions be made on a part sparingly supplied with separate nerve-fibres, such impressions may travel to the sensorium, only along one fibre, in which case, only a single impression will be perceived. It has been assumed, that each cutaneous nerve-fibre ends in a pencil of delicate filaments, for the supply of a definite circular or oval area of the skin, the diameter of which has been estimated at probably about $\frac{1}{400}$th of an inch; but the filaments of adjacent nerve-fibres are supposed to pass into contiguous areas, so that the exact spot of the body, which is the seat of a single impression, is recognized by the aid of compound impressions. On this view, a theory is offered as to the sense of locality possessed by the skin, viz., that the smaller these areas—*i. e.*, the more numerous and closer the nerve-fibres—the greater the acuteness of this sense of space. (Fick.)

The curious observation has been made, that a part endowed with a finer sense of space, *feels* a part less endowed in that respect, and not the latter, the former; when, *e. g.*, the finger touches the forehead, it is the finger which feels the forehead, and not the forehead the finger. For this experiment, the two parts of the skin must be of the same temperature; for when two regions of the skin of different temperatures, are brought in contact, a double sensation is produced.

A useful instrument named an *æsthesiometer*, consisting of a graduated bar, having a fixed and movable point attached to it, has been devised for testing the relative sensibility of different parts of the skin, in cases of more or less complete *anæsthesia*, or *paralysis of sensation*.

There is no necessary relation between the delicacy of the tactile sense in a part, and its common sensibility, for in some regions of the skin, where the perception of tactile impressions is very perfect, common sensibility is much less marked than it is in other regions, where the sense of touch is much less acute. In the soles of the feet, the arm-pits, and the flanks, parts endowed with but little tactile sensibility, the sensation of tickling can be most easily excited; but on the ends of the fingers, where the delicacy of touch is highly developed, it is difficult to produce tickling.

Experiments have been made to determine the relative sensibility of the skin, by placing weights on different portions of the body, and ascertaining what is the minimum weight capable of exciting a tactile impression. It was found, by Aubert and Kammler, that a body, weighing two milligrammes, and covering one square millimetre, could be distinguished upon the face; whereas, on the pulp of the fingers, a body occupying the same area, must weigh from ten to fifteen milligrammes, in order to produce a distinct sensation of pressure. But the sensibility of the face was considerably diminished, when the minute hairs covering its surface were shaved off. The left half of the body is said to be, as a rule, better able to appreciate weights by their pressure on the skin, than the right half. The sensation of pressure in different parts of the skin, does not exhibit such marked differences as that of the sense of space. Increase of pressure is more easily perceived than a diminution of the same. (Panum and Dohrn.) It is easier to distinguish small differences with light weights, than with heavy ones. (Weber and Fechner.) Slight differences in two weights, can be more easily discriminated, when these are placed on the same part of the skin a little time after each other, than when they are simultaneously applied close together.

Pressure only does not, however, convey to the mind a correct idea of weight, for bodies appear heavier when their pressure is made to act on a small surface of the skin than when it is extended over a larger area. The sensation of the muscular effort required to resist the pressure, is a much more important guide in judging of the weights of bodies. Thus Weber has shown, that if the eyes are closed, and two weights, one of which is somewhat heavier than the other, be placed, one on either hand, we are unable to appreciate any difference between them, so long as the hands are supported on cushions; but the moment the hands are raised, the muscular effort thus made, immediately informs us of a difference between the weights. The muscular sense is here brought into play.

As already mentioned, the mere contact of an object with the organ of touch only conveys the notion of resistance; but a notion of the *extent* of *surface* of an object is arrived at by alterations in the relative position of the organ of touch and the object touched, and in this we are also assisted by the muscular sense, which gives us a knowledge of the positions of the arm and hand.

The knowledge of the *dimensions*, *shape* of *surface*, and *distance* of objects, is obtained in two ways. Either we judge by the relative distance and position of two or more, or even of many, points of the sensory surface of the part of the body employed in the act of feeling, with the motion or situation of which, we are accurately informed by the cutaneous sense of locality; or we touch in succession several points of the objects to be examined, with the same sensory surface of the body, and then by the extent and direction of the movements necessarily performed by us in these acts, judge of the size and form of the object in question. In the former case, our perceptions become more accurate when the acts of contact with the foreign body are successive, than when such contacts take place simultaneously; moreover, the acts of contact, when successive, must neither be too quick nor too slow, or we lose the power of judgment from them. In these applied uses of the sense of touch and the muscular sense, for the formation of compound ideas and notions, we are, in practice, greatly and habitually assisted by the sense of sight.

Long-continued impressions on the nerves of touch leave after, or secondary impressions, which sometimes persist for a long period; as, when a person in the habit of wearing a ring, believes that he still feels it, after he has left it off. These *after impressions* are dependent on some altered condition of the skin. The general after effects of continued and successive tactile impressions are remarkable. Thus, if the hand is brought into contact with a rapidly revolving disc, the edge of which is provided with uniform fine teeth, alternate and distinct tactile sensations of contact and non-contact are produced. With a certain velocity, these remain distinct, but at very high velocities, the two sensations become less so, and resemble in character those known as rough or woolly. Still more rapid revolutions of the disc at length produce uniform sensations, which are comparable with that of smoothness or even with that of complete polish. (Valentin.)

Continued uniform pressure upon any portion of the skin ceases, after a time, to produce any impression; but when the pressure is no longer uniform, *i. e.*, if it be lessened or augmented, its presence is immediately noticed. If the pressure, after having been uniformly kept up for any length of time, be removed, an after sensation, as usual, remains.

The mind, as already mentioned, generally refers the sensations of touch to the part of the skin stimulated, but, under certain circumstances, they are referred altogether to the exterior. Thus, when an object is brought into contact with parts destitute of nerves, like the hairs or nails, the effect is communicated through them to the sensory portion of the skin from which they grow, and gives rise to sensations which are distinctly referred to the insensible hair or nail. In the same manner, the sensations of touch are sometimes referred to the extremity of a foreign body in contact with the skin; thus, if a stick be held by one end, and its other end be brought into contact with any object, we perceive a twofold impression, one where the stick is held, and another which is referred to the end of the stick touching the foreign body.

The sense of touch can be excited, as it is said, subjectively, or by *internal* causes; thus, the sensations of formication, creeping, or tingling, may arise independently of external influences: such tactile sensations are of frequent occurrence.

The sense of touch is capable of being *educated*, as is well seen amongst the blind, whose tactile discrimination is so acute and delicate, that they are able to read sentences in raised letters, to distinguish the inscriptions and impressions on coins, and frequently even to recognize shades of color, which escape the notice of the eye, by means of differences of texture and surface. It has been found that the sense of space or locality, as determined by experiments with the compasses, or with the æthesiometer, is well developed in the case of blind persons, not only in the hands, but even in all the other parts of the body. In persons born without arms, the sense of touch in the toes sometimes becomes, by dint of education, so highly developed, that these can be used in the same manner as the fingers. The influence of habit, in improving the delicacy of the tactile sense, is illustrated by the mode in which factory girls can detect and join the finest fibres of silk and cotton, in the spinning machines. The Bengalee female silk-throwsters are said to be able to distinguish by the touch as many as twenty different degrees of fineness in the fibres of the cocoons. It has even been alleged, in regard to the influence of education on the tactile sense, that an improvement, in this respect, in any part, on one side of the body, is accompanied by a corresponding improvement in the same part of the body on the opposite side.

Hallucinations connected with the sense of touch are not uncommon. A familiar example is that afforded by crossing two fingers of the same hand, and rolling between them a small rounded body, such as a pea, when the sensation of a double body is experienced. If the point of one's tongue be so touched, two tongues are felt. A stick pressed simultaneously against the upper and lower lip, appears to be straight, but if one lip be moved sideways, or if both be moved in opposite directions, the stick seems to be broken; if this experiment is performed before a looking-glass, the illusion is at once dispelled. (Czermak.) If a body, such as a ball, be touched with sticks of different lengths, whilst the eyes are turned in another direction, it will be found that, when the sticks are carried round the body, this appears smaller the greater the length of the stick, the angle which is then described being much smaller. These are errors of judgment, based on sensations with which we are not familiar. In transplantation of a portion of skin from one part to another, as in the formation of a new nose by a flap of skin turned down from the forehead, but still left connected with that part, by a narrow bridge of integument, the sensations are, for a time, referred to their old seat; so that, when the new-formed nose is touched, the sensation is felt as if it were in the forehead. This is the case, however, only so long as the nerves in the connecting bridge of skin are undivided, and it is uncertain whether the mistake can be corrected by the aid of vision. If the connecting nerves are cut through, all sensibility is temporarily lost in the new nose, until, after a time, new nerves enter it through the cicatrix.

The Sense of Temperature.

By means of a peculiar modification of sensation, we appreciate those intermolecular motions, which cause changes of *temperature in the skin*, and thus arrive at notions of the temperature of external objects, whether these affect us by actual contact and conduction, or, without contact, by radiation.

Impressions of heat or cold, or *thermal sensations*, can only be communicated to the extremities of the nerves of the skin or adjacent parts of the mucous surfaces; that is, through some *recipient sensory surface;* for it is impossible to excite such impressions, by acting directly on the very nerves which ultimately transmit them. For example: on the raw surfaces left after destruction of the whole thickness of the skin in burns, the sense of temperature is lost, heat or cold, applied to such surfaces, merely producing pain. The skin over the ulnar nerve, behind the elbow, does not exhibit greater sensibility to moderate differences in temperature, than other parts of the body; but when the degree of heat or cold passes certain limits, pain is the only sensation experienced; a mixture of ice and water applied over this nerve, causes intense pain in a few seconds. In the same manner, the contact of frozen quicksilver, or solid carbonic acid, with the skin, causes a painful sensation similar to that produced by touching red-hot iron.

Thermal sensations are excited by bodies, the temperature of which ranges between 50° and 117° Fahr.; above or below those points, objects no longer excite the feeling of heat or cold, but cause a sensation of pain. Water at a temperature of about 130° no longer feels warm, but imparts a slight burning sensation; in the same manner, the feeling of cold is no longer experienced a few degrees above the freezing point, painful sensations being then produced.

Sensations of heat or cold are not absolute, but are relative to the temperature of the part of the body acted upon. Hence, objects appear warm or cold, in proportion to the temperature of the body at the time of contact, imparting the sensation of warmth or heat, when their temperature is higher than that of the body, and the feeling of cold, when it is lower. The temperature of the hand is a few degrees lower than that of parts nearer to the centre of the body; hence, when placed in the armpit, it feels cold, whereas the axilla appears warm to the hand. So long as the temperature of the skin remains constant, thermal sensations in it are very slight, or altogether absent, for the various temperatures of the skin of the cheeks, hands, feet, and other parts, do not usually excite in us sensations of temperature. When the amount of heat given off, or taken up, in a stated time, is proportionally great, the sensation of heat or cold is persistent; for sensations of temperature are experienced, not only during the immediate changes of temperature in the skin, but also during the passage of a certain quantity of heat through it.

The experiments of Weber show that the sense of temperature is much modified, according to the extent of surface of the body exposed to the impression, the greater the extent of surface exposed, the more intense being the impression produced. Thus, if the whole of one hand be placed in water heated to a temperature of 102°, and one finger alone of the other hand, in water heated to 104°, the temperature of the former will appear much higher than that of the latter. Slight differences of temperature can be recognized by the whole hand, which are not perceptible if a single finger be employed.

The sensibility of the skin to differences of temperature, varies in different individuals and in different parts of the body; this is undoubtedly in part dependent on differences in the degree of thickness of the epidermis. The tip of the tongue, the face, the fingers, and the soles of the feet, are the parts in which thermal sensations are most easily and acutely felt. It is said that, with the tip of the tongue, variations of temperature of even $\frac{1}{2}$° can be distinguished. The sensibility of the left hand to temperature is more delicate than that of the right. Weber found, that if both hands are immersed in separate vessels of hot water, the left hand always appears the warmer, even though the temperature of the water in which it is immersed, be 1° or 2° colder than that in which the right hand is placed.

The sensations excited are more intense, when the alterations in the temperature of the skin are rapidly effected. When a portion of the skin is cooled by immersion in water at a low temperature, say 55°, and is then immersed in water at 68°, a feeling of heat is experienced for a few seconds, whilst the temperature of the skin rises, but a permanent sensation of cold then follows, because the temperature of the water is still much lower than that of the skin. Cold bodies, which are good conductors of heat, such as the metals, appear to us colder than other bodies of the same temperature, which, like wood, are bad conductors of heat, because the quantity of heat absorbed in a given time from the skin is greater. The sensation of burning is communicated to the hand by air at a temperature of 302°, by wood at 212°, and by mercury at 144°. Those bodies which have a high specific heat, and which absorb and render latent large quantities of heat, also act more powerfully on the thermal sense.

It is supposed, that the giving up of heat by the skin, which takes place when a cold body is brought into contact with it, causes a contraction of the cutis and its papillæ, and that the taking up of heat, which ensues when a warm body is brought into contact with the skin, leads to the dilatation of those parts, and that, in this manner, the nerves are acted upon, and the sensory impressions of cold and heat are produced. This refers to cases, in which the heat is conducted into or from the body, by some material substance, either solid, fluid, vaporous, or gaseous, actually in contact with it. But the nerves which receive and convey thermal impressions to the sensorium, are also affected, as we know, by radiant heat coming to, or issuing from, the body. In this case also, the heat is still conducted to or from the extremities of the nerves, by material substance, viz., that of the skin itself, the temperature of which is elevated, or depressed, by the reception, or loss, of radiant heat. Accordingly, the nerves are probably not excited by the entering or departing radiant heat itself, but by the heat conducted to, or from, them by the warmed or cooled skin.

In parts of the body, in which there is incomplete paralysis of sensation, the sense of temperature remains, or is the last to disappear; so that paralyzed parts, which are no longer sensible to pressure or pricking, still remain sensible to the influence of heat and cold. This may be explained, either by supposing the existence of special sets of nerves for the conveyance of thermal impressions, or the occurrence of peculiar changes in the path of the proper tactile sensations in the cord, or in the corresponding sensorial centres in the cerebrum.

The mucous membrane of the alimentary canal generally, is incapable of receiving impressions of thermal differences, though these are felt in the mouth, pharynx, and, for a short distance, down the œsophagus. In the stomach or intestines, cold or hot water produces corresponding sensations of cold or heat, only when the temperature of the adjacent skin of the abdomen is itself lowered, or elevated, by the conduction of heat to or from it, from or to the alimentary canal in which the hot or cold water is contained.

Subjective sensations of heat or cold are very common in cases of disease. That of cold, in the stage of ague, and that of heat, in febrile conditions of the system, bear no relation to the actual temperature of the body. The former is supposed to be due to a contracted state of the muscular coats of the bloodvessels, and of the non-striated muscular fibres of the skin, which conditions diminish the supply of blood to the part. The heat in fever, is attributed to the increased activity of the circulation, and of the metamorphosis of the tissues.

Sensations of heat may be confounded with tactile impressions, even in those parts of the body in which sensibility is most highly developed. (Fick and Wunderli.)

It is supposed that the reason why the only sensation experienced on immersing the hand or foot in mercury, or a warm fluid, as that of a ring around the limb at the surface of the liquid, is due to the fact that the portion of the limb immersed, being subjected to uniform pressure, its papillæ are not excited, but only those corresponding to the line at which the different pressures exerted by the air and by the fluid, meet.

The Organs and Sense of Touch in Animals.

Amongst the *Vertebrata* in Mammalia, as in Man, the whole surface of the body possesses not only common sensibility and a general sense of touch, except in those species in which, as in the Armadillo, the integument presents a thick, horny, or bony covering, but the proper tactile sense is principally exercised by parts provided with nervous papillæ. In most Quadrumana, the tips of the toes and *fingers*, where the sense of touch is most acute, are abundantly supplied with papillæ; and the under surface of the prehensile tail of certain monkeys, which likewise has many papillæ, is also a tactile organ. In many Rodentia the pulps of the digits are highly sensitive. In the Bat the sense of touch is extraordinarily developed in the *wings;* by which means it can avoid objects during its flight, even when the eyes are extirpated. (Spallanzani.) The *whiskers* or *vibrissæ* of the Carnivorous tribes, especially in the cat and seal, and also those of many rodents, as in the rabbit and hare, are endowed with very acute tactile sensibility. The bulbs of these vibrissæ are very large, and each receives a nerve, often of considerable size, derived from offsets of the infra-orbital branch of the fifth cranial nerves; when these whiskers are cut off, the sense of touch in the animal is seriously impaired.

But in the greater number of Mammalia, the *lips* and the end of the *nose* are the special seats of touch, many, as the ant-eaters, mole, hog, tapir, and elephant, being provided with a movable snout. In the rhinoceros there is a soft, hook-like expansion of the upper lip, which is constantly kept moistened, to insure its sensibility. The snout of the tapir is more developed than that of the pig; and the tactile sensibility of the tip of the elephant's trunk, is second only to that of the human hand. The skin of the zoophagous Cetacea is very remarkable for the thickness and density of its structure. The true skin consists of a thick, dense, whitish, opaque, fibro-cellular layer, provided with innumerable elongated papillæ, which enter into corresponding depressions on the under surface of the thick black epidermoid layer. These papillæ are half an inch or more in length, and are said to be supplied with nerves as well as vessels. It has been supposed by many familiar with the habits of the whale, that the sense of touch is very acute in these animals, especially for undulations transmitted through the water; and that, in this way, the whales can communicate with each other when alarmed. In Mammalia, the soft, movable, papillated *tongue* is undoubtedly used as a tactile organ.

The general nature of the covering of the skin in *Birds* offers a great obstacle to the reception of external impressions. The toes have but few nerves, and are usually so covered on their under surface, as scarcely to be regarded as tactile organs; whilst the extremities of the anterior limbs or wings are utterly unsuited to such a function. The sense of touch in birds must, therefore, be chiefly resident in the bill; this, though usually hard, is soft in the snipes and woodcocks, which search for their food in marshy ground, and also in the flat-billed water birds; in these it is abundantly supplied with nerves. In a few birds the tongue is papillated, and probably serves as a tactile organ.

Amongst *Reptiles* the sense of touch is but feebly developed. The tongue of the Ophidia, and of many Saurian reptiles, is considered to be an organ of touch.

The naked, soft skin of the *Amphibia* is abundantly supplied with nerves, and is, therefore, well adapted for the reception of sensory impressions; but the proper tactile sense resides principally in the skin over the tip of the jaws, and also in that of the limbs.

In *Fishes* the soft lips, the parts about the mouth, and, in some species, the pectoral fins, are the seats of the sense of touch. In a few, as in the gurnards, there are digitate appendages connected with the pectoral fins, which seem to be endowed with tactile sensibility.

In the Mollusca, touch must be supposed to reside in the general soft integument; but it seems to be more acute near the orifice of the mouth in the Cephalopods and Gasteropods, and at the margins of the mantle of the Lamellibranchiata. Many are provided with retractile feelers or other appendages, specially connected with the head; such as the horns of the snails, and the arms of the cuttle-fish. The tentacles of the Polyzoa and other Molluscoida are highly sensitive.

In the Annulosa, highly developed tactile organs exist, as, *e. g.*, the jointed antennæ possessed by insects, which present the most remarakable varieties of form, and, in certain cases, are so important, that when they are removed these creatures are no longer able to follow their usual habits. In the ants, the antennæ seem to be employed as means of communication between different individuals. In certain cases the palpi and feet may assist the tactile sense in insects. In the Crustacea, generally, the antennæ, of which there are frequently two pairs, are undoubtedly sensitive tactile organs, and the prehensile jaws and feet may also conduct tactile impressions. The Myriapods also have articulated feelers. The Arachnida, which have no antennæ, possess palpi; but the exquisite sense of touch which the spinning Spiders must possess, resides probably in the feet, especially in the terminal joints. The ovipositors of many insects probably possess a tactile sense, to inform these animals as to the fitness of the place of deposit for the eggs. In the Worms, there are frequently found appendages in the form of folds, threads, or setæ, often arranged in rows on the body, frequently in whirls, or they are confined to the head, a region which, even if destitute of appendages, is highly sensitive to the touch. Amongst the Annuloida, the revolving-wheels of the Rotifera generally, and the proboscis of some species, are probably tactile. The marine parasitic species have a soft, sensitive integument. The succulent feet of the Echinodermata are also remarkably irritable, if not sensitive.

In the Cœlenterata, the ectoderm, especially over the oral tentacles, possesses keen excitability; but they do not apparently exhibit much discriminating sense, seizing all objects alike. The Protozoa, destitute of a nervous system, exhibit no tactile organs.

In all cases, the integument of the Vertebrata consists of a vascular cutis, or true skin, covered by a non-vascular epidermic layer, and is moreover, often provided with various appendages. Some of these, such as the hairs, spines, nails, claws, hoofs, and even the horns of the Mammalia, are epidermic structures, formed on papillæ or matrices, developments of the cutis or true skin. In a few instances, the dense dermal plates of the rhinoceros, and the bony plates of the armadillo, are formed apparently, beneath the epidermis, on the surface of the true skin, and are partly vascular tissues; they belong to the so-called *dermal* skeleton or *exo-skeleton*, as distinguished from the *endo-skeleton* or skeleton proper.

In Birds, feathers take the place of hairs, being, like these, epidermic formations, developed upon papillæ at the bottom of follicles, and having, like hairs, a root sheath, one layer of which, however, closes the young follicle, and for a time invests the growing feather, but ultimately is broken through, and falls away. The quill of the feather consists of fibres and flat scales, and, for a time, contains a portion of the vascular papilla or pulp; the shaft, barbs, and barbules, consist of a pith composed of polyhedral cells, and of an outer firmer layer, composed of flattened epidermoid scales.

Amongst Reptiles, the thick coriaceous integument of certain saurians, the osseous plates of the crocodiles, the scales of serpents, and the horny coverings of the Chelonia, are also epidermic formations, beneath which, in the crocodiles, bony matter is formed, constituting a dermal skeleton; but in the Chelonia, the bony case beneath the horn, named the plastron and carapace, is formed by the expansion and coalescence of parts of the internal skeleton.

The soft integument of the Amphibia, in many cases, almost resembles a mucous membrane.

In Fishes, the integuments are either soft, as in the eels, in which they are still provided with minute scales, or they are covered with the characteristic larger dermoid scales, the pattern and formation of which, have led to important distinctions in this large class; sometimes they present numerous dermal plates or spines. The scales consist of an outer laminated, and sometimes canaliculated, shining layer, composed of the so-called *enamel* or *ganoin*, and of a deep layer, which may be horny, fibrous, or even bony; in the latter case, it sometimes contains Haversian canals. The bony scales, and also the bony plates and spines, of certain fishes, are partly epidermoid structures, but are probably also in part, formed by conversions of the outer layer of the dermis; they have great analogy to teeth, especially to the teeth of fishes themselves. The spines of the fins of fishes, are also dermal structures, belonging to the exo-skeleton, and not to the internal skeleton.

The cutaneous glands, both sebaceous and sudoriferous, are found in all Mammalia, except when the integument is covered with horny or bony plates. In Birds, the chelonian and ophidian Reptiles, and Fishes, the cutaneous glands appear to be wanting; in the Saurian Reptiles, they are small and few; in the Amphibia, cutaneous glands of a peculiar structure are very abundant. The so-called glands, or mucous canals and follicles, along the lateral line of fishes, corresponding with the Savian bodies of the torpedo, are believed by Leydig, to be really sensory organs, contained in depressions, or canals, formed in the integument. They are lined with epithelium, and often contain a knob-like projection, abundantly supplied with nerves derived from branches of the fifth pair, or of the pneumogastric nerve. Some of the so-called cutaneous glands of the Amphibia, just described, may be of a similar nature. They must be acted on by irritating solids, fluids, or gases, present in the water, just as irritants act on the soft tongues of the mammalia; they may thus give warning of danger.

In the soft-skinned Mollusca, Molluscoida, Annelida, and Cœlenterata, the outer layer of the integument does not consist of flattened epidermoid scales, but of soft spheroidal cells with thick walls, often covered with a structureless membrane. The laminated shells of these animals, when they exist, are formed by the calcification of a nacreous excretion from the surface of the true skin beneath the thin epidermis, which is best seen at the growing margin of the shell. The calcareous substance is almost entirely carbonate of lime. The shell of the tunicated Molluscoida is formed, not by excretion, but by the conversion of their cellulose integument, into structures resembling shell, cartilage, bone, or even dentine. (Huxley.)

The calcareous shell of the larger Crustacea, the horny coverings of others, the chitinous integument of the Myriapoda and many of the Insecta, and the coriaceous skin of the Arachnida, are sub-epidermic structures, formed by various thickenings, fibrillations, calcifications, and other changes of the epidermis, and of certain layers excreted beneath it. The spines, hairs, and microscopic scales of Insects are epidermic.

Cutaneous glands are represented in the non-vertebrate animals, by peculiar cæcal follicles and tubes found in a few Annelida, Insecta, and Mollusca. The chromatophores of certain Mollusca, and the thread-cells of the Cœlenterata, are not glands.

The nervous substance of the warm- and cold-blooded animals must be adapted to suit very different ranges of temperature.

THE SENSE OF TASTE.

The Organ of Taste.

The *tongue* is the organ chiefly concerned in the sense of *taste;* other parts of the mouth, however, especially the under surface of the *soft palate*, and the anterior pillars of the *fauces*, are also endowed with this sense.

The tongue is a muscular, vascular, and nervous organ, made up of two symmetrical halves, joined in the middle line. It is composed chiefly of muscular fibres, some of which are proper to it; but the greater number proceed from other parts, to its base and under surface. The apex, sides, upper surface, and forepart of the under surface, are free; by its under and back part, it is attached to the lower jaw, the hyoid bone, and the styloid process of the temporal bone; it is also connected with the pharynx and soft palate, by means of the anterior and posterior pillars of the fauces; and lastly, it is connected to the epiglottis and neighboring parts, by reflections of the mucous membrane of the mouth. A fold of this membrane, seen beneath the tip of the tongue, forms the *frænum linguæ*. The apex of the tongue is thinner and narrower than the rest of the organ; the dorsum, or upper surface, is convex, and presents along the middle line a furrow called the *raphé*, which ends behind in a depression, the *foramen cæcum*.

The dorsum, edges, and tip of the tongue, have a peculiar rough appearance, differing altogether from the smooth character of the mucous membrane covering its under surface and the rest of the interior of the mouth, and depending on the presence of little eminences, named *papillæ*. These somewhat resemble the papillæ of the skin, and are of three kinds, named the *filiform*, *fungiform*, and *circumvallate* papillæ.

The *filiform* papillæ, so called from their thread-like shape, are by far the most numerous; they are found closely set over the anterior three-fourths of the tongue, being especially well marked along the central part; at the sides and tip, they become shorter, and are arranged in oblique, or almost transverse parallel ridges, which gradually disappear as they run to the under surface of the organ; they are of a whitish color, being covered by a dense and thick epithelium, which is divided, at the apices, into a brush of very fine filaments (Fig. 70, *a*). They are set, for the most part, with a slight inclination backwards. Their use is mechanical, and they aid in the tactile sense, but not directly in the sense of taste.

Fig. 70.

Fig. 70. Diagrammatic view of the papillæ of the tongue (Kölliker). *a*, filiform papilla, showing its vascular core or centre, with its secondary papillæ, buried in the thick epithelium, which ends in a brush, of hair-like character. *b*, fungiform papilla. with its numerous secondary papillæ, and thin epithelial covering. *c*, circumvallate papilla, its secondary papillæ, and their epithelial covering.

The *fungiform* papillæ, so called because they are expanded at their free extremities, are scattered irregularly over the dorsum of the tongue, chiefly over its anterior half; they are not so numerous as the filiform papillæ, but are of larger size; they are of a deep red color, and are covered by a thin soft epithelium (Fig. 70, *b*). The *circumvallate* papillæ, also red, and covered by a delicate epithelium, are still fewer in number, varying from eight to fifteen, but they are the largest in size. Each is placed at the bottom of a cup-shaped depression (Fig. 70, *c*), so as to be encircled by a little furrow or trench, which being itself surrounded by an elevated rim, or diminutive vallum, has given rise to the name circumvallate, applied to these papillæ. They occupy the back part of the tongue, forming two principal rows, like the letter V, with its point turned backwards. Numerous large and soft papillæ, intermediate in form between the circumvallate and fungiform kinds, are situated behind, and on each side of, the circumvallate papillæ; they pass, towards the borders of the tongue, into irregularly notched and parallel ridges. Further back, these papillæ subside, and the mucous membrane becomes smoother and thinner, and is marked by numerous elevations and recesses, corresponding with the lingual mucous glands and follicles beneath it, some of which open into the bottom of the foramen cæcum.

The corium, or vascular part, of the circumvallate papillæ (Fig. 70, *c*), and of the elevated rim, by which each is surrounded, is prolonged into numerous secondary papillæ, which are buried in the thin and smooth epithelial covering. The fungiform papillæ likewise present numerous little conical secondary papillæ (*b*), covered by the epithelium. The filiform papillæ also have, at their points, numerous secondary papillæ (*a*), concealed in the thick brush of filamentous epithelium. Besides these secondary papillæ, found on the larger and so-called compound papillæ, numerous minute and simple papillæ, resembling the secondary papillæ, exist everywhere, between the compound papillæ.

Many of the muscular fibres of the tongue pass into the mucous membrane and its papillæ, presenting the peculiarity of dividing and subdividing before they enter these parts. Both the compound and simple papillæ receive vessels and nerves. Each papilla contains one or many vascular capillary loops, according to its size. In the fungiform and circumvallate papillæ, especially, the nerves are very numerous, and, in the latter, very large; they are usually said to terminate in loops; but it is possible that many at least end by fine free extremities, a mode of termination seen in the tongues of some animals.

Each half of the tongue is supplied by three nerves. Of these, two are sensory, viz., the lingual or *gustatory* branch of the inferior maxillary division of the fifth cranial nerve, and the lingual branch of the glosso-pharyngeal. The former is distributed to the mucous membrane and papillæ at the forepart and sides of the tongue, the latter to the mucous membrane at the base and side of the tongue, and, it is said, especially to the circumvallate papillæ. The remaining nerve, the *hypoglossal*, or ninth cranial nerve, supplies the muscular substance of the tongue, and is the motor nerve of this organ.

The *soft palate*, its central depending *uvula*, and its lateral *arches*, or *pillars*, will be hereafter described with the other parts concerned in deglutition. Its mucous membrane, which is smooth and delicate, and provided with short soft papillæ, and numerous glands, is supplied by branches derived from the superior maxillary division of the fifth cranial nerves, and also by branches from the glosso-pharyngeal nerves.

Taste.

The true sense of taste in the tongue is confined to the posterior third of the dorsum of that organ, the under surface of its apex, and a line along its edge, about a quarter of an inch wide. It is most marked on the hinder part of the organ. It also resides in the anterior pillars of the fauces, the soft palate near its attachment to the hard palate, and the hinder portion of the latter. (Stich and Klaatsch.)

The experiments of Reid show that the glosso-pharyngeal is a nerve of special sense, as well as of common sensation, and also an afferent reflex nerve; for not only are unmistakable signs of pain produced by irritation of the nerve in the living animal, but division of this nerve, on the two sides, destroys the power of taste in the parts of the tongue supplied by it. Division of the fifth cranial nerves, or of their gustatory branches, immediately produces loss of common sensibility in the anterior part of the tongue; for the application of caustic potash, or of a hot iron to this part of the organ, in the living animal, does not then give rise to any sign of pain. The power of taste in the forepart of the tongue, has also been said to be destroyed by division of the fifth nerve; but, as just mentioned, it would seem that except at its edges, and beneath its apex, parts which probably receive filaments from the glosso-pharyngeal, the forepart of the tongue is naturally destitute of the sense of taste. Hence the apparent loss of taste, after division of the fifth nerves, may have been only a loss of common sensibility in the animals experimented on, in consequence of which sapid bodies no longer produced any signs of sensation, either common or special. There is an obvious difficulty in determining very precisely whether an animal tastes or not. In cases of paralysis in man, taste has been destroyed without the common sensibility, and the latter has been lost without the former. This would show, either that different nerves, or different filaments of the same nerves, minister to the two forms of sensation. Whilst it is certain that the glosso-pharyngeal is a nerve of taste, the gustatory office of the so-called gustatory branch of the fifth nerve is by no means so clearly established.

It has been observed, that in cases of paralysis of the facial nerve, above the origin of the chorda tympani, in the human subject, the sense of taste is much diminished, or even altogether lost. Experiments made by Bernard, on living animals, further show, that if the facial nerve be divided within the skull, the sense of taste is impaired on the corresponding side of the tongue; whilst the tactile sensibility remains unaffected. Division of this nerve, after it has issued from the stylo-mastoid foramen, does not in any way affect the sense of taste. Hence, the integrity of the chorda tympani, which is destitute of sensory fibres, appears to be essential for the proper exercise of taste. Perhaps the effects which follow its division are owing to the diminution which then takes place in the secretion of the saliva.

A state of solution being an essential condition for the perception of gustatory impressions, sapid bodies are tasteless, when applied in a dry state, to a dry or coated tongue, and a free flow of saliva is of great use in the exercise of the sense of taste. Contact of the sapid body being also essential, it is necessary, for very accurate tasting, that this contact be perfect; hence, a substance, if solid, must be pressed between the mobile tongue and the palate, so that after it has undergone solution, it may diffuse itself over the whole of the gustatory mucous membrane. In this way, the savors of fruits, and the flavors of wines, become remarkably developed, after these have been carried over the whole of the mucous surface. A short time must elapse, after contact with the tongue, before sapid bodies excite the sense of taste. This varies according to the substance. Saline solutions are most quickly perceived, sweet solutions less quickly, then acid, and lastly, bitter substances. Even when mixed, different substances are tasted separately and consecutively. It is interesting to note, that the so-called colloid bodies which have a low, diffusive osmotic or dialytic power are tasteless; whilst the crystalloids, which dialyze rapidly, are generally sapid. (Graham.)

Since many sapid substances, such as quinine and salt, are inodorous, the sense of taste must be regarded as independent of smell, as it is of touch, or of the sense of pain. But, in judging of the flavors of different substances, we are assisted by the organ of smell, for many flavors are incomplete without the help of the olfactory sense, and may be diminished by closing the fauces, so as to shut off the nose. The existence of nasal polypi also interferes with taste. Certain odors are undoubtedly confounded with taste. Thus, when eating garlic or vanilla, the sensations referred to the gustatory sense, are no longer perceived when the nose is kept closed. The vapor of chloroform, when inhaled through the nose, conveys the sensation of an odoriferous substance, although it is a sapid body. (Stich.) Deglutition necessarily assists in the appreciation of the taste of sapid substances, when these are grasped by the fauces.

The sense of taste is, in some respects, allied to the sense of touch. In the first place, it is not dependent on a purely special nerve, for the cranial nerves, through which this sense is exercised, are also common sensory nerves. All the parts concerned in taste, are also endowed with common sensibility. Moreover, for the perception of a gustatory impression, it is essential that the sapid body be brought into actual contact with some portion of the sensory surface, otherwise gustatory impressions cannot be excited. The same is true, however, of the sense of smell, if we regard odors as material. Lastly, as in the case of touch, there is an absence of any complex recipient apparatus, the only structures entering into the formation of the gustatory surface, being the mucous membrane of the mouth, with its nervous and vascular papillæ, which closely resemble those of the skin, but are more delicate. The sense of taste differs, however, from that of touch, by being limited to a particular portion of the surfaces of the body, and still more remarkably, by the peculiarity of its exciting causes, which are *specially chemical* and not mechanical agents. In this respect, as already mentioned in the section on Sensation in general, taste is evidently closely allied to smell. The organ of taste, indeed, shows greater resemblance to that of touch in structure, than in function. In both, the local application of the exciting stimulant, is necessary; but in the one, the action on the nerve is purely physical, and is merely transmitted mechanically, through the tissues which cover the nerve; whilst in the other, the sapid substance must be fluid, or dissolved, must penetrate the tissues to reach the nerves, and must exercise some very special, and probably chemical action upon them, so as to excite the nervous energy. Bodies differing widely, in both their physical and chemical nature, may excite allied tastes, as for example, bitter saline substances and vegetable bitters. The causes of the sensation of taste, and of the sapidity or insipidity of different substances, are not further known; much less can we, at present, offer any explanation of the varieties of tastes excited by different sapid bodies. The sensations induced by them, however, are more distinguishable from each other, and therefore clearer, and more definable by language, than those of smell.

Certain properties of substances, which have been named the mechanical savors, such as the peculiar sensations communicated to the mouth, by oleaginous, amylaceous, or watery substances, are distinguished by the highly developed tactile sensibility of the tongue. They are due to the different degrees of consistency, presented by these bodies. The so-called mealy, sandy, pasty, astringent, and alkaline impressions, are probably merely special tactile impressions. Pricking, stinging, and biting sensations are perhaps modifications of pain, like the smarting of blistered surfaces. The burning occasioned by some substances, as mustard, and the feeling of cold excited by others, as peppermint, are apparently referable to the sense of temperature; for both these impressions are independent of taste.

Some substances, when introduced into the mouth, only excite tactile impressions, and hence are called *tasteless;* all insoluble bodies belong to this class. Other substances, such as sugar, excite both tactile and gustatory impressions; and a third class of bodies, such as smelling-salts and volatile oils, besides producing tactile and gustatory impressions, also excite corresponding odoriferous sensations; thus, again, showing the alliance between taste and smell. Lastly, some metals, when placed in contact with the mouth, produce no impression on the gustatory sense, merely exciting tactile and odoriferous sensations. Those substances which act on the gustatory sense, are called *sapid.* Of these, there are four different kinds, viz., the sour, the saline, the bitter, and the sweet; tartaric acid, common salt, quinine, and sugar, are examples of such substances. Solutions of sour and sweet substances, are said to be best distinguished, when they are applied to the tip of the tongue, whilst saline and bitter tastes are best perceived, when brought in contact with the root of the tongue. Acids and bitters are said to be the most readily detected of all sapid substances; then saline, and lastly, saccharine. It has been found, that 1 part of sulphuric acid in 10,000 of water, and 1 part of sulphate of quinine in 33,000 of water, can be detected, when carefully compared with pure water. (Valentin.) Sugar cannot be tasted, when there is less than 1 part in 80 or 90 of water; and of common salt, 1 part is necessary in 200 of water.

After the tongue has been exposed alternately, in succession, to two or more allied tastes, the gustatory sense becomes blunted, losing its power of discriminating between them. This is probably due, in part, to some continuance of each impression on the gustatory nerves; but, it is perhaps principally dependent on small portions of the sapid bodies remaining dissolved in the epithelial coat. The discriminating powers of the sense of taste, are, on the other hand, assisted by contrasting different flavors. If the tongue be exposed to a temperature much above, or much below, the normal temperature of the body, both its tactile and gustatory sense become impaired or suspended. Thus, after immersion of the tongue in a mixture of broken ice and water, or in water at a temperature of 125°, for about a minute the taste of sugar cannot be perceived, and the tactile sensibility of the tip of the tongue is also diminished.

Gustatory impressions sometimes arise independently of the contact of sapid bodies with the organ of taste. A drop of pure water placed on the tongue, gives rise to a slightly bitter taste; and the same sensation is caused by touching its surface near the root, with a dry glass rod. A cool saline taste, somewhat resembling that of nitre, is produced by directing a small current of air on to the tongue. (Henle.) Electricity also gives rise to gustatory impressions, a peculiar saline taste being caused, when the front of the tongue is stimulated by electrical shocks; whilst a constant current produces a sour taste at the positive pole, and an alkaline impression at the negative pole, perhaps from decomposition of the secretions of the mouth. Indistinct gustatory sensations may be induced by striking sharply and lightly the lingual papillæ. A mechanical stimulus applied to the fauces and root of the tongue, induces a bitter taste, and a sensation of nausea.

The sense of taste presents different degrees of development in different individuals, being, in some, much more acute than in others. Like the other senses, it is improved by cultivation, as is well seen in the case of wine- and tea-tasters. In colds, and diseases and injuries of the brain, the sense of taste is lost, either temporarily or permanently.

Impressions made upon the sense of taste, remain for a certain time; those produced by some substances lasting for a considerable period. As a rule, they endure longer than the after impressions of smell, hearing, or sight. The after taste, or *arrière gout*, has its seat at the root of the tongue; like taste, it can be strengthened by pressing, rubbing, and moving the sapid body between the palate and the tongue. The after taste frequently differs from the original one; a bitter substance may give rise to a sweet after impression, or a sweet substance to a bitter one.

Subjective gustatory impressions sometimes occur, as, for example, metallic, sweetish, and sanguineous or nauseous tastes. These subjective sensations have been supposed to proceed from changes in the composition of the blood, which are perceived in the interior of the organ of taste. They may be due to errors in the circulation through the nervous centres connected with taste; and sometimes merely to an altered condition of the secretions of the mouth. A person suffering from the disease known as saccharine diabetes, in which sugar exists in undue quantity in the blood, is not, however, conscious of a sweet taste, and can readily distinguish sugar; whilst a taste of blood is usually only experienced when the cavity of the mouth contains blood.

The sense of sight, as is well known, materially influences the gustatory sense; for, in the dark, sapid substances lose half their relish.

The uses of the sense of taste are, besides that of imparting gratification, chiefly to assist in the choice of food. This is often peculiarly manifested in invalids or convalescent persons.

The Organs and Sense of Taste in Animals.

Amongst the *Vertebrata*, the sense of taste is probably well developed in all Mammalia, most of which masticate their food, and so retain it long enough in the mouth to enable it to act as a sapid body. The chief organ of taste is the tongue, but the soft palate, as in Man, may be supposed to be likewise concerned in this sense. The dorsum of the tongue is generally very rough, and frequently presents horny papillæ, or, as in the Carnivora, horny recurved spines, which aid in grasping the food in mastication, or even in rasping flesh from bones, and in cleaning the coat of the animal itself; but the surface at the root and edges is softer and is probably more actively gustatory. The shape of this organ presents many and striking varieties. In some of the suctorial bats it is singularly modified, presenting a circular series of elevations, provided with proper muscles and forming a sucking organ. In the ant-eater it is long, slender, and worm-like, and can be protruded with great swiftness for a distance of sixteen or eighteen inches. The tongue of the Cetacea generally, is broad, and only slightly movable; in the herbivorous species, Sirenia, it has a complicated papillary surface; but in the zoophagous kinds, or true Cetacea, it has neither circumvallate nor conical papillæ, but merely minute tactile papillæ; it has been doubted whether these animals possess the sense of taste. Some Mammalia have a second, or even a third accessory tongue, as, for example, the bears.

The organ and sense of taste appear to be incompletely developed in *Birds*, which, for the most part, swallow their food quickly, and indeed, seem to be rather guided in their choice of it by the sense of sight. The tongue usually has a horny covering at its tip, and is destitute of papillæ, except near its base. In the parrots, however, the tongue is roundish, large, and fleshy, and is covered with papillæ; in the flamingo it is also large, soft, and papillated. In a few species it is cleft at the point, as in the ravens. This organ often presents peculiarities connected with its use in the taking of food; thus, in the humming-bird it is rolled into a sucking tube, and terminates in hair-like filaments for retaining the nectar of flowers; in the toucan it is fringed with bristly processes for trying the ripeness of fruit; and, in the woodpeckers it is barbed with inverted processes for seizing insects.

In Reptiles the tongue also appears to be rather a tactile than a gustatory organ, for they almost all swallow their food immediately it has been seized; so that the sense of taste is probably quite subordinate. The chameleon has a very large tongue, which, when protruded, is worm-like in shape; it possesses a central canal, and terminates anteriorly in a club-shaped extremity, smeared over with a viscid secretion; when darted out after prey, it appears longer than the whole body of the animal. In the crocodiles the tongue is closely attached to the floor of the mouth; but in the chelonian reptiles it is free. The turtles have a small and hard tongue; in the land tortoises it is soft and papillated, and is undoubtedly endowed with gustatory sensibility. In the Ophidia, and in the small lizards, the tongue is bifid, and is lodged in a sheath, from which it can be protruded with a darting quivering motion.

Amongst the Amphibia the tongue is soft; it lies inverted in the mouth, both in the frog and toad, and is used as a prehensile organ. The structure of the lingual papillæ, and especially the mode of termination of their nerves, have been closely studied in the frog. By some it is held that, in the large fungiform papillæ, the nerves end in fine fibres, which are attached to the bases of the large terminal nonciliated epithelial cells, whilst the ramified muscular fibres join the ciliated epithelium at the base of the papillæ. (Stilling, Waller.) It has also been stated that the nerves end in narrow cells, or rods, which pass up to the surface between the true epithelial cells. (Axel Key.) We shall find a similar structure, and this is an interesting fact, in the olfactory mucous membrane of the nose. The less perfect Amphibia, such as the proteus and siren, appear to be destitute of a tongue.

In Fishes generally, the sense of taste is probably but imperfectly developed, even if it exist. Some, indeed, have no tongue at all; for they bolt their food instantaneously, as it is taken, so that the gustatory sensibility, if present, must be seated in the palate and fauces. Others possess a large tongue, which presents prehensile teeth rather than sensory papillæ.

A sense of taste, or, at all events, a power of discriminating proper food, would seem to be present in most, if not all, of the non-vertebrate animals, even in the Infusoria, many of which appear to exercise a faculty of selection in regard to their food. The seat of this sense is probably here too in the neighborhood of the entrance of the digestive apparatus; but its proper organ or organs are unknown. The so-called tongue of the Cephalopods, and the odontophore of the Gasteropods, are rather accessory digestive than gustatory organs. The larvæ of insects, the feeding propensities of which are so strong and peculiar, nevertheless present no special organ of taste.

THE SENSE OF SMELL.

The Organs of Smell.

The nasal cavities, or *nasal fossæ*, situated between the base of the cranium and the roof of the mouth, at the upper and fore part of the face are the seats of the organs concerned in the sense of smell. The roof, sides and floor of these cavities are formed by the surrounding bones of the cranium and face, see Fig. 72. The ethmoid bone, which forms part of the floor of the cranial cavity, is, however, the most immediately concerned in the formation of the olfactory part of the nasal fossæ; its cribriform plates, Fig. 72, enter into the formation of the roof; its cellular lateral portions, 3, constitute the convoluted sides of the upper part of the cavity; whilst its median septum, 4, assists in forming the partition which divides one nasal fossa from the other. The fore part of the fossæ is completed, at the sides and in the median line, by the nasal cartilages, Fig. 71, 4, which are adapted to the margin

Fig. 71.

Fig. 71. Lateral view of the bones and cartilages of the nose. 1, left nasal bone. 2, ascending part of the superior maxillary bone. 3, lachrymal groove for the lodgment of the lachrymal sac. 4, cartilages of the side, and alæ of the nose. (Arnold.)

of the great nasal aperture seen in the bones, as well as to the bony septum. These cartilages give form and stiffness to the visible part of the nose; they are provided with certain small subcutaneous muscles. The nasal fossæ open anteriorly by the apertures called the *anterior nares*, or nostrils, which are provided with short hairs, or *vibrissæ*, to prevent the introduction of coarse foreign bodies. Behind, the fossæ open, by two orifices called the *posterior nares*, into the upper part of the pharynx, see Fig. 73. The side of each fossa, next the middle line or *septum* (Fig. 72, 4, 5), is smooth, but the outer side is more or less convoluted, owing to the presence of three delicate, shell-like bony expansions (Fig. 73), viz., the upper, 2, and middle, 3, turbinated portions of the ethmoid, and the lower independent turbinated bone, 4. Below each turbinated bone is a longitudinal recess, named a meatus. These three *meatuses*, named *superior*, *middle*, and *inferior*, communicate with certain cavities, called *sinuses*, formed in the ethmoid, sphenoid, frontal, and upper jaw-bones.

At the anterior nares, the skin which covers the nose externally, is continuous with a lining membrane, called the *nasal mucous membrane*, *pituitary* or *Schneiderian membrane*, which lines the interior of every part of the nasal fossæ, and secretes a fluid naned *pituita*. This membrane, besides being continuous with that lining the pharynx and the Eustachian tubes, is also extended into the several sinuses just mentioned; moreover, it is prolonged, on each side, through a small canal, leading from the nasal fossæ, into the lachrymal sac, and thus becomes continuous with the *conjunctiva*, or mucous membrane of the eyelids.

The nasal mucous membrane varies in different regions. First, there is a *lower* region, in the neighborhood of the nostrils, in which

Fig. 72.

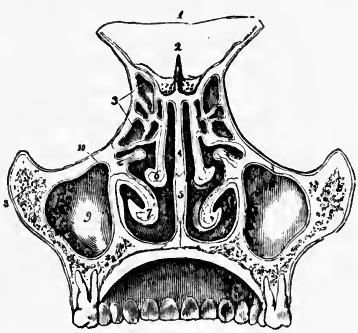


Fig. 72. Transverse vertical section across the nasal cavities, opposite to the middle of the hard palate; the anterior section, seen from behind, so that the hinder surface of the upper teeth is seen below. 1, part of inner surface of cranium. 2, projection between the two cribriform plates of the ethmoid bone. 3, cells in the left lateral mass of the ethmoid bone. 4, median septal portion of the ethmoid bone; the narrow dark space on each side of this, is the olfactory region. 5, the vomer, or bony septum nasi. 6, the middle turbinated portion of the ethmoid. 7, the left turbinated bone. 8, section of the malar bone. 9, maxillary sinus, or antrum of Highmore, which communicates with the nasal cavity. (After Arnold.)

the mucous membrane is firm, pinkish-white in color, provided with fine papillæ, and covered with a squamous epithelium, consisting of several layers of cells. Secondly, there is a *middle* region, in which the mucous membrane is dark-red, soft, provided, in places, with numerous little mucous glands, and covered with a cylindrical, or columnar ciliated epithelium. Thirdly, there is an *upper* region, very *narrow*, from side to side (see Fig. 72), and corresponding with the roof, and the ethmoidal portion of the convoluted sides and septum, where the mucous membrane is pulpy, of a yellowish-brown color, provided, in its upper part, with peculiar short glands, somewhat like the sebaceous glands of the skin, and covered with cylindrical or columnar epithelial cells, having flattened ends, but being destitute of cilia. Between the cells of this epithelium, are found other, finer, spindle-shaped columns, or rods, which are of a varicose shape, and project beyond the surface; they are named the *olfactory cells.* (Schultz.) Lastly, the various sinuses connected with the nasal fossæ, are lined by a thin, red, smooth, ciliated mucous membrane. The lining membrane of the lower region next to the nostrils, is usually dry; whilst that of the other two regions, and of the sinuses, is constantly moist, either with simple mucus, or with the special secretion of the small glands in the upper region. The lower region is also the thinnest, and least vascular; the sinuses are much more so; whilst the upper and middle regions are thicker and more vascular, especially over the turbinated bones.

The nerves supplying the nasal mucous membrane are derived from three sources. First, from the nasal and anterior dental branches of the fifth pair of cranial nerves, which are distributed to all its parts; secondly, from the vidian, naso-palatine, descending palatine, and spheno-palatine branches of the sympathetic nerve, which also probably have a general distribution; thirdly, there are the terminal branches of the first pair of cranial nerves, or *olfactory nerves*, Fig. 73, 2. The

Fig. 73.

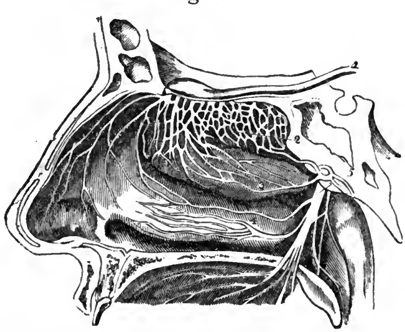


Fig. 73. Vertical section through the right nasal fossa, showing the outer side of that fossa, with a part of the base of the cranium, the palate, and the nose. 1, the olfactory tract ending anteriorly in the olfactory lobe, or bulb, resting on the cribriform plate of the ethmoid bone. 2, superior turbinated portion of the ethmoid bone, corresponding with the upper part of the olfactory region, and covered with the network of the branches of the olfactory nerves. 3, middle turbinated portion of the ethmoid bone, covered with a few olfactory nerves, and also forming part of the olfactory region. 4, lower turbinated bone, receiving only branches of the fifth nerve, 5, which also supplies the palate. The anterior region of the nasal fossa receives branches also derived from the fifth nerve. (After Arnold.)

latter proceed from the olfactory lobes, 1, within the cranium, and pass through the small openings in the sieve-like plates of the ethmoid bone, to gain the upper part or roof of the nasal fossæ. They are about twenty in number, are arranged in each fossa in three groups, one of which supplies the roof, another distributed on the surface of the cellular part of the ethmoid bone, 2, 3, as low down as the middle turbinated bone, whilst an inner group spreads out on the upper third of the nasal septum. The branches of these nerves everywhere form a close network; they are composed of small, soft, nucleated, gray, or non-medullated nerve-fibres, having no white medullated fibres amongst them; their ultimate fibrillæ are said, by Schultz and others, to join the rod-like bodies, named the olfactory cells, which are found between the ordinary epithelial cells. Through these cells, which are regarded by Schultz as nervous structures, or bi-polar nerve-cells, the ends of the olfactory nerves are believed to reach the very surface of the membrane, in the form of delicate threads, which project between the ordinary epithelial cells, and are kept constantly moistened by the secretions of the part.

Of the three regions of the nasal fossæ, the upper one alone, which corresponds to the narrow part to which the olfactory nerve is distributed, is the true *olfactory region* or *seat of smell;* the middle region, ciliated like the rest of the air-passages, may be regarded as the *respiratory part* of the nose, which organ, indeed, is placed, for obvious purposes, in the track of the respiratory passages; the lower region is the common aperture to the two others, and, being nearer the surface, is more cutaneous in its character. The region of the sinuses is not directly concerned in smell; but these cavities may act as reservoirs for odorous emanations, so as to prolong olfactory impressions; they chiefly aid, however, in providing moisture for the interior of the fossæ. Even the lachrymal secretions, or tears, having performed the office of moistening the eyeballs, pass, through the canal already mentioned, into the nasal fossæ, and serve a similar purpose.

Odors.

It is not yet known why certain bodies are odorous, and others not. As regards the physical condition proper to odorous bodies, it is certain, however, that most, if not all, are volatile, or else actually aëriform or gaseous, at ordinary temperatures; but all volatile bodies, or bodies capable of assuming the form of vapor, are not necessarily odorous, as, for example, water. Certain bodies, or fine particles of them, conveyed mechanically through the air to the nose, may cause smell, either on being dissolved in the fluids of the nose. or by being previously volatilized, or by giving off odorous effluvia, which are then dissolved in the fluids of the nose.

The chemical constitution of odorous bodies, offers no certain explanation of this peculiar quality. For example, some elementary substances, as chlorine and copper, produce the sensation of smell, whilst others, as nitrogen and silver, do not; again, of allied chemical substances, such as the salts of copper and silver, the former are odorous, whilst the latter are inodorous. As a rule, imperfectly oxidized substances, or those which have a tendency to further oxidation, such as essential oils, have a strong odor; but even a most perfectly oxidized body, such as carbonic acid, possesses an odor, though this may rather depend upon its irritating property, when it is of a certain strength; for, if diluted, it has no smell. Many perfectly oxidized bodies do not smell at all, as, for example, water; some smell very slightly, as sulphuric, phosphoric, and chloric acids. Hyper-oxygenated bodies, if volatile, as peroxide of hydrogen, produce a peculiar odor, but not if they are fixed, like the peroxides of barium and manganese. Ozone, whether it be a polarized condition of oxygen, of oxygen combined with itself, or in some other state, possesses a very remarkable pungent odor. It is remarkable, that hydrogen, the lightest and most diffusible element with which we are acquainted, produces, when in combination with all other elements, excepting oxygen, the most powerful odorous bodies with which we are familiar. Thus, with nitrogen, it forms the pungent substance, ammonia; with chlorine, hydrochloric acid; with cyanogen, a hypothetical radical composed of carbon and nitrogen, both of which are inodorous, hydrocyanic acid; with carbon only, the carburetted hydrogens (coal-gas, and marsh-gas); with phosphorus, phosphuretted hydrogen; and with sulphur, sulphuretted hydrogen. All these compounds are relatively unstable, and prone to oxidation. With oxygen in equal proportions, hydrogen forms the inodorous, though volatilizable body, water.

Although, then, neither the physical nor the chemical conditions of matter, which are distinctive of odorous bodies, can be clearly defined, volatility on the one hand, and a condition of chemical instability, especially that of imperfect oxidation, on the other hand, are probably the two most general characteristics of odorous bodies.

If the cause of odor generally is but little known, still less are the *qualitative* characters of different odorous bodies, and the causes of the varieties of smell, understood. In this part of the inquiry we are met with singular perplexities and contradictions; thus, bodies differing much in nature, have similar kinds of odor; as, for example, garlic and the vapor of arsenic, as this becomes changed into arsenious acid; phosphorus, also, has a garlicky smell. At present all attempts to classify odors are futile. The *quantitative* power, or intensity of odor, in certain bodies, is very remarkable. It is very intense, and capable of propagation to great distances, in the case of camphor, turpentine, ether, and musk; whilst, on the other hand, it is feeble, and acts only at short distances, in the case of caoutchouc, gum, or sugar, the odors of which latter substances may be due even to associated aromatic impurities.

The extreme *divisibility* and minuteness of the ultimate odorous particles, is evidenced in such facts, as that a drop of ether will impregnate the atmosphere of a large apartment, and that a grain of musk has been kept for ten years, emitting constant odor, without, it is said, suffering any appreciable loss of weight. This fact has been quoted in support of an idea, that odors are not caused by material emanations from the odorous substance, but perhaps by subtle motions, or undulations, of a peculiar kind, originating in the odorous bodies themselves, and exciting similar undulations in the atmosphere, or in some special medium, which, impinging on the olfactory nerves, produce the sensation of smell. But for such an experiment to be conclusive, the hydrometric condition of the musk, at the commencement and end of so long a trial, should be accurately determined, otherwise it becomes quite valueless, even though other many obvious causes of fallacy be eliminated. Moreover, strongly odorous bodies, such as turpentine or ether, do positively waste, so that the inference, at present, is in favor of the actual transmission of material particles through the air, until they are brought into contact with the nasal mucous membrane. The interposition of a solid body between an odorous substance and the nose, prevents the transmission of the odor, which, therefore, cannot be conducted, like sound, by vibrations, nor, like light, by undulations. Odorous emanations are capable of being absorbed by porous substances or materials, such as cloth, especially, it is said, by dark cloths, which are therefore unsuited for medical men and nurses in fever hospitals. When absorbed by fresh animal charcoal, odors are, like the compound gases, partially subjected to decomposition by a process of slow oxidation.

Smell.

Every portion of the nasal mucous membrane possesses common sensibility and its modifications, being alike capable of receiving impressions of touch, temperature, and pain. This is owing to the presence of the branches of the fifth pair of nerves. It is probable even, as already hinted, in speaking of carbonic acid, that many strong vapors, such as ammonia, acetic, and other volatile acids, not merely affect the true nerve of smell, but also the branches of the fifth nerve, causing that combination of odor and irritation, which characterizes the so-called *pricking* or *pungent* odors. These substances appear indeed, to act, when highly diluted, as odors, but when less diluted, or concentrated, as irritants, just as they act on the cutis, and excite a pricking or smarting sensation when the cuticle is removed.

The sense of smell proper, however, is shown, by the following facts, to be dependent on the action of the olfactory nerves, and of the special olfactory lobes or centres. First, the size of these nerves and lobes, in animals distinguished for their perfect sense of smell; secondly, the abundant distribution of the nerves in the upper part of the nose; thirdly, the absence of the sense of smell in congenital deficiency of the olfactory lobes and nerves, of which an instance occurred in a street scavenger at Leipsic; fourthly, the loss of the sense of smell in diseases affecting the olfactory lobes, and the upper or olfactory region of the nose; and lastly, the similar loss of smell, following the division or destruction, of these lobes in animals. This experiment is most easily performed in young animals. (Biffi.)

It was found by Magendie, that dogs in which the olfactory nerves had been destroyed, still searched for, and discovered, meat. This fact, he thought, justified the extreme conclusion that the olfactory nerves were not in any way concerned in smell; but it is rather to be explained, by reference to the instinct and habits of the dog, which would lead it to search for food, even though it could not smell. Paralysis of the fifth cranial nerve, diminishes the healthy secretion of the nasal mucous membrane, and so interferes with the sense of smell.

The *conditions* necessary to smelling are these. First, the transportation through the air of the odorous particles, in the manner already mentioned, to the nose; this is more rapid when the air is in motion, and takes place in the direction of that motion. Secondly, the solution of the odorous particles in the moisture of the olfactory mucous membrane. Thirdly, their passage, by means of diffusion, into the substance of the extremities of the olfactory nerves, which, as already mentioned, approach to, or even reach, the epithelial surface. Fourthly, the particles must exercise a chemical action upon the extremities of the nerves; and there are reasons for supposing that the presence and action of oxygen, in conjunction with the odorous substance, are necessary to this process. (Graham.) Fifthly, the nerve itself must be endowed with the property of receiving such substance, or its resulting compounds, and of being chemically acted upon by them. Sixthly, the olfactory lobes must be capable of discriminating the effects of the special impressions excited at the extremities of the nerves. Lastly, the nasal cavities must contain air; for, in man, and probably in all air-breathing animals, the sense of smell fails in the water; and according to Weber, when water, or even solutions of odorous substances, are poured into the nose, smell is temporarily suspended. These effects have been referred to abnormal changes in the epithelial and other cells of the nasal mucous membrane.

The physical conditions necessary to the exercise of smell, are influenced by the respiratory movements, and by the state of moisture of the nasal mucous membrane. Inspiration is obviously necessary to smell, as the means of drawing the odorous particles into the nose. In ordinary expiration, smell is almost entirely absent; but if the mouth be filled with tobacco-smoke, or the vapor of chloroform, and this be forced from the pharynx, through the posterior nares, into the nasal fossæ, its characteristic odor is at once, though less distinctly, perceived. The act of inspiration is, however, essential as a mechanical aid; for holding the breath prevents the exercise of the sense of smell. In gentle inspiration, odors are faintly perceived; in strong, quick inspirations, as in sniffing, to appreciate the odor of wines and flowers, or very faint odors, they are most acutely perceived, because a larger quantity of the odorous substance, passing by the middle and lower regions, impinges, in a given time, with a certain force, upon the olfactory region; the upward direction of the stream of air thus inhaled, carries it at once to that part of the nose. Hence, too, closing one nostril diminishes the force of odorous impressions. The presence of large polypi in the nose, destroys smell. In quiet breathing, the air passes chiefly through the lower and middle regions of the nose, viz., through its respiratory portion, and only a limited quantity reaches the upper or olfactory region; whilst, in stronger inspirations, the stream of air is drawn upwards, a movement said to be favored by the form of the inferior turbinated bones.

The natural moisture of the mucous membrane is indispensable to the exercise of smell. The secretion of the nasal glands is abundant; it is slightly alkaline, but otherwise its nature is unknown. From the depth, protected character, and position of the *olfactory region*, out of the course of the respiratory air-current, its moisture is preserved from evaporation; this is also checked by the copious supply of mucus from the nasal fossæ and their communicating sinuses, and by the continuous lachrymal secretion. These fluids also serve to charge the inspired air-current with a due proportion of moisture. The necessity for the moist condition of the olfactory membrane, is shown by the absence of smell when this is more than ordinarily dry, as in certain stages of a cold. In perfectly dry air, odors are perceived with difficulty. The opposite condition, of too great an amount of moisture, as in other stages of a cold, is also unfavorable to smell. The deficiency of smell noticed after certain surgical operations, in which the nerves regulating the secretion of the nasal mucous membrane have been divided, may also be due to the unusual state of dryness of the membrane, which ensues under those circumstances. In all these abnormal conditions, however, the loss of smell may be owing to inflammation, or some other changes in the membrane or its nerves.

In reference to the necessity for the presence and co-operation of oxygen for the exercise of the olfactory sense, and for some oxidation of the odorous substance on the surface of the nasal mucous membrane, it has been stated, that odors are imperceptible, when inspired mixed with carbonic acid or nitrogen; but, in the former case, the excitability of the olfactory nerves may be suspended by the specific action of the carbonic acid; and, in the latter case, careful observation has shown, that some sense of smell is still retained. This, however, may be due to oxygen already dissolved in the fluids of the nose; and it is difficult to inhale pure nitrogen sufficiently long, to avoid this source of fallacy without risk to life. The remarkable pungency of ozone, suggests the possibility, that, even if odorous substances be not oxidized at the surface of the membrane, and so, whatever their nature, be rendered soluble in the nasal mucus, yet ordinary oxygen may operate as a special stimulant to the excitability of the olfactory nerves, and thus increase the intensity of the sensation.

Whether the odorous substances are first oxidized or not, some *chemical reactions* probably occur between them and the substance of the olfactory nerves; and these reactions, of the nature of which we are entirely ignorant, are probably, moreover, of some special nature, in the case of each distinct odor. In this way, we might account for the differences between different smells. Various irritants, such as mustard, and acetic acid, produce quite similar impressions upon the nerves of common sensation, as, for example, when they are applied to the denuded cutis; but these two substances, and all others having different odors, produce distinct impressions of smell. Hence, not only do different odors, most likely, produce different chemical effects on the olfactory nerves, but these nerves, and their nervous centres, must experience special physiological reactions in the discrimination of different odorous substances. Our knowledge concerning this apparently very simple sense is, however, extremely limited.

It has been said by some, but is doubted by others, that mechanical irritation can produce odorous impressions on the olfactory nerves. Direct mechanical irritation of the olfactory nerves, causes neither pain nor reflex movements; but irritation of the nasal branches of the fifth pair, is followed by pain and reflex movements. The galvanic or other form of electrical stimulus, produces a sensation of tickling, and sneezing. It has been said that galvanism excites an ammoniacal smell, when the negative pole is applied to the olfactory membrane, but an acid smell, when the positive pole is employed. (Müller.) These effects may be owing to chemical decomposition of the mucus; and, according to general authority, the electrical stimulus does not directly excite the special properties of the olfactory nerves.

The *acuteness* of smell, in regard to certain substances, is very remarkable, $\frac{1}{33,000}$th part of ammonia, $\frac{1}{200,000}$th part of bromine, $\frac{1}{1,000,000}$th part of sulphuretted hydrogen, and even $\frac{1}{13,000,000}$th part of musk, being perceptible when mixed with common air. Odorous impressions are quickly blunted, and are of very short duration. It has been conjectured, that we do not perceive double sensations of smell from the two nostrils, because of the plexiform arrangement and non-medullated structure of the olfactory nerve-fibres; but, to this, it may be objected, that we can, by attention, discriminate the sensation conveyed through each nostril, even when the same odor is presented to both; and, moreover, when different odors are presented to the two nostrils, we do not perceive a combined impression or sensation; but each smell is alternately, or separately perceived. The olfactory sense, like the other senses, varies in different persons, both as to its quantitative and qualitative character, some having the sense obtuse, and others acute, in regard to all odors, some discriminating particular faint odors, as those of certain flowers or fruit, and others not being able to perceive them. The sense may be trained, by exercise and attention, alternating with due intervals of rest and abstinence from the action of the same odor. On the other hand, it may be blunted, by the habitual presence of any one odor, at least, as regards that odor itself. Why certain odors are agreeable, and others disagreeable, to persons generally, is not known; in the case of individuals, the utmost diversity prevails in this respect, habit especially, being a second nature.

Whether *after-smells* due to states of the nerves, occur similarly to after-tastes, is difficult to decide, for particles of odorous substances retained on the mucous membrane, may cause prolonged sensations. Subjective sensations, due to changes in the composition of the blood, or to disturbances in the circulation through the olfactory nervous centre, have been less commonly observed in regard to smell than to the other senses. Maniacal persons, however, often complain of disagreeable odors.

The sense of smell is allied, not only by its chemical and physical phenomena, but also physiologically, to the sense of taste. It ministers but little to the intellectual faculties of man, but rather to his bodily wants, aiding him in determining his choice of food, and of such products of the animal, vegetable, or mineral world, as are agreeable to this particular sense; and often teaching him to avoid injurious or disagreeable substances, especially gases and vapors. It is, in particular, the sanatory sense, serving to test the air we breathe, and, if duly attended to, warning us of the deleterious emanations from decomposing organic matter.

Smell is very acute in certain uncivilized tribes, as amongst the

Peruvian Indians, who can distinguish by it, in the dark, persons of different races. It is recorded of James Mitchell, who was born blind and deaf, and was necessarily dumb, that he could distinguish persons, and recognize strangers, by the sense of smell.

The Organs and Sense of Smell in Animals.

The sense of smell is undoubtedly very generally possessed by animals. Besides being a source of enjoyment, and serving the important office of aiding animals in the pursuit of living prey, and in their search after, and selection of, other proper food, the sense of smell often assists them in the avoidance of their natural enemies, likewise informs them of the presence of individuals of their own species, and, as in Man, doubtless frequently warns them of the existence of noxious vapors, and other substances.

This sense exists, in a more or less highly developed state of perfection, in all the Vertebrata, whether they breathe air or respire in water, for it is present even in all fishes. But, as we know and understand smell, it is, in its highest degree, an atmospheric sense, and, in fishes and all lower aquatic animals which possess it, must exist in some modified, and probably less refined, though acute, form. In a very few of the Cetacea, alone amongst the Vertebrata, is this sense entirely wanting.

In all the air-breathing Vertebrata, *i. e.*, in Mammalia, Birds, Reptiles, and the perfect Amphibia, the olfactory organs, however highly or simply developed, are situated in the course of the respiratory passages, the nasal fossæ being, in all cases, pervious backwards, opening behind, usually into the upper part of the pharynx, but, in the very lowest forms, into the mouth. In the Mammalia, the nose is, as a rule, highly developed; the nasal fossæ are capacious; the horizontal cribriform plate and the lateral cellular parts of the ethmoid bone are large, and, as well as the turbinated bones, often highly complex; the various sinuses in the adjacent bones are well developed, though they are not directly concerned in the sense of smell. The anterior part of the nose is cartilaginous, and is provided with muscles; it forms the so-called muzzle of the dog, the snout of the pig and tapir, and the trunk of the elephant. In the seals, walruses, beavers, and other diving mammals, the nostrils are slit-like, very movable, and capable of being tightly closed at will; a similar provision is met with in many burrowing animals; and in the camels, also, the large movable nostrils can be closed against the tornado of the desert. In many bats, the nose is developed into singularly formed folds or leaflets, which are supposed to collect odors. But perhaps the most remarkable modification of the anterior part of the nose, is the elephant's trunk, which is a double tube, containing thousands of muscular bundles, and is not only a prehensile organ, and a hydraulic pipe, but forms the usual respiratory passage. In this animal, besides the ordinary adjacent sinuses, which are very large in the frontal bones, there are others in the temporal, parietal, and occipital bones, all of which communicate with each other.

In certain carnivorous animals, as in the dog and seal, and also, but not to such an extent, in many Ruminants, as in the sheep and deer tribes, in all of which the sense of smell is very acute, as witnessed in the quick recognition of the presence of Man exhibited by the stag, and in the almost fabulous power of certain dogs in following the scent of their prey upon the ground, provision is made for a vast extension of the nasal mucous membrane, by a most singularly complex lamination of the spongy bones, constituting the structure named the *labyrinth*. The olfactory nerve is not, however, commonly distributed over this complicated portion of the nose, so that it only indirectly subserves the olfactory sense. Possibly it delays, retains, and subdivides the atmosphere laden with odorous matters, in its intricate passages, and so facilitates their oxidation; or it may be intended to aid in warming and moistening the air. In the Cetacea the nasal cavities are reduced to simple, long, narrow canals, destitute of turbinated bones, and having no adjacent sinuses. As in the rest of the Mammalia, the posterior nares open into the pharynx, but the anterior nares, instead of being placed near the extremities of the upper jaw, are found far back on the top of the head, where they form sometimes, as in the sperm whale and narwhal, one, but usually two, blow holes, through which the water taken in by the mouth in feeding, and stored up in two strong muscular cavities, can be forcibly expelled. The high position of these openings readily brings them to the surface when the animal desires to breathe, an act which can be accomplished even whilst the mouth is submerged and engaged in catching prey. The nasal fossæ of the Cetacea, exposed as they are to the frequent passage of water through them, as well as of air, have little or no concern in the function of smell. Thus, in the true whales, the olfactory nerves are proportionally very small, and judging from what takes place in ourselves when water or even solutions of odorous substances are poured into the nose, it may be conjectured that they do not distinguish the presence of odorous particles in the water, but only that of those conveyed to them through the air taken in during inspiration. In the porpoises and dolphins, however, the olfactory nerves are absolutely wanting; and these creatures, therefore, can possess no true sense of smell, though they, and indeed the other Cetacea, may receive impressions of an irritating character from substances diffused through the water, acting on the extremities of the branches of the fifth pair, which, as usual, supply the nasal mucous membrane.

Amongst *Birds* generally, the sense of smell does not appear to be so highly developed, as to qualitative power in the individual, though it may be as acute as in Mammalia. There is no longer a cribriform plate to the ethmoid bone, for the olfactory nerves pass each through a single foramen. The nasal cavities are proportionally smaller and less complex in their interior than in the Mammalia, but the turbinated bones are sometimes convoluted, and even laminated. The posterior nares often coalesce before they open into the pharynx. The anterior nares are never provided with movable cartilages, as in the Mammalia. These openings differ much in size, position, and structure; they are generally wide and open, but are narrow in the heron, often protected by stiff feathers, as in the crows, or covered by a scale, as in the rasorial birds; they are usually placed on the sides of the bill, but sometimes at its base; and occasionally, as in the apteryx, at its apex. Judging from the relative size of the chief turbinated bone, and of the olfactory nerves, the wading birds appear to possess the most perfect sense of smell. In the vultures, also, the nose is much prolonged, and the olfactory nerve is large; they are said to smell carrion at very great distances. Nevertheless, the idea still sometimes entertained, that the vulture scents its dead prey from the enormous altitudes at which it flies, has been disproved, the discovery of its food being effected through the agency of vision.

In *Reptiles* the sense of smell seems to be less developed than in birds; there are few or no complications of the surfaces of the nasal fossæ. The posterior nares open, in the Saurians, into the pharynx; but in the Chelonia and Ophidia through the palate, into the mouth. In the crocodiles the nostrils can be closed when the animal is beneath the water; and these apertures being placed at the end of their long snout, they are able to lie almost completely submerged, concealed, and watching for their prey.

The perfect *Amphibia* also present two posterior nares, opening through the palate into the mouth; but in the Proteus family this opening is placed so far forwards that it passes through the upper lip; in the Proteus itself, the nasal mucous membrane is plicated, as in Fishes. In their early fish-like larval condition, the organs of smell in the Amphibia are merely simple depressions or recesses, like these parts in fishes, but they are provided with cilia.

The sense of smell is probably, as already stated, somewhat modified in aquatic animals; but it is, nevertheless, judging from the size of the olfactory nerves and lobes, actively exercised in *Fishes*. These animals do not inhale the atmosphere into their bodies, for they have no lungs. The nasal fossæ form two blind recesses or culs-de-sac, opening externally on the fore part of the head, but in almost all cases shut off posteriorly from the mouth or pharynx. The water, through which medium the odorous particles must be transported, enters these nasal culs-de-sac, and there comes in contact with the delicate membrane supplied by branches from the large olfactory lobes. This membrane often has its surface increased by being thrown into variously folded or plaited laminæ; sometimes forming longitudinal, and sometimes singularly complicated, radiated plicæ.

In the Cyclostomata, the nasal apparatus is single, and is sometimes closed at the bottom; but in the Myxinoids, for example, the cavity is prolonged backwards, by a special trachea-like canal, which perforates the palate, and is there provided with a membranous valve, which can be opened or shut. The lepidosiren is another example of the communication of the nose with the mouth, in fishes. In the minute and simple amphioxus, the nasal cul-de-sac is single, median, very superficial, and ciliated in its interior.

The Mollusca, being chiefly aquatic, must receive odors through the water. In the Cephalopods, the organs of smell are supposed to be two cavities, placed near the back of the eye, each containing a papilla; the nerves which pass to them arise from the side of the optic nerve or ganglion, and perforate the cartilaginous capsule of the eye, before entering the papillæ. The cuttle-fish is said to exhibit a strong aversion to certain odorous bodies. It has been suggested that the smaller buccal tentacles of the nautilus are possibly connected with the sense of smell. In the other Mollusca, the sense of smell is also supposed to reside in the sensitive tentacles, often found at the entrance of the mouth and respiratory apparatus, beyond which no special organ for this sense has yet been discovered in those animals.

In some of the Annulosa, as in the Crustacea, the habits of the animal (as of the lobster, for example, which enters the lobster-pot in deep water, probably attracted by the smell of the bait), justify the inference, that they possess an olfactory sense; but, by what part or organ, unless by the smaller antennæ, this is exercised, is unknown. The open cavity in the base of these antennæ, which admits the water to its interior, may be, as Rosenthal thought, the organ of smell. In the Insects, as in the carrion-flies and others, there is also reason to infer the existence of a very perfect sense of smell; for they are attracted by putrid meat, some of them even depositing their ova in plants possessing that odor. Bees are possibly attracted to very distant clover-fields, or other feeding-grounds, by means of an olfactory sense. In the Insecta, it is also conjectured that the antennæ are the smelling organs. Dugès found that, after the removal of the antennæ, insects did not manifest their usual cognizance of the vicinity of smells. Possibly the palpi may also be concerned in the exercise of this sense. In the necrophorous beetles a curious double, cushion-like structure exists in a cavity in the broad upper lip, which is well situated for an organ of smell. Many insects suffer irritation from fumes or vapors entering their respiratory tubes or trachea; but there is no reason to consider such sensations as allied to true smell. In certain of the Molluscoida and Annuloida ciliated recesses, or disc-like spots, situated on the head, may serve as olfactory organs; but in many of them, as well as in the Cœlenterata and Protozoa, the existence of smell is doubtful, and certainly no special organ of that sense is known.

THE SENSE OF HEARING.

The Organs of Hearing.

The auditory apparatus is usually described as consisting of three parts: the *external* ear, Fig. 74, *b*, *m;* the *middle* ear, or *tympanum*, *t;* and the *internal* ear, or *labyrinth*, *s*, *c*.

The external ear consists of the *pinna* or *auricle*, and the *external auditory meatus*, or *canal*. The pinna, the part usually called the ear, Fig. 74, presents an outer border or rim, called the *helix;* a curved ridge, internal to this, is the *antihelix;* within the antihelix is the principal fossa, called the *concha* (a shell), *b*, which leads directly into the external auditory meatus, *m*. In front of the concha, and overlapping the meatus, is a small pointed eminence, generally studded

Fig. 74.

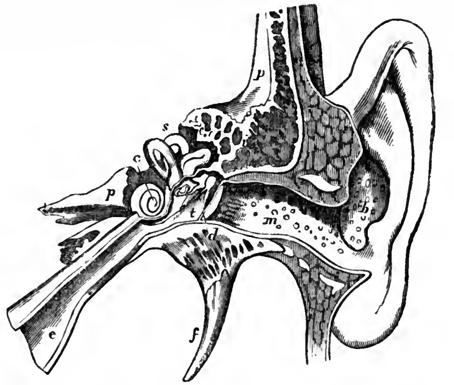


Fig. 74. Diagram, showing the parts of the external, middle, and internal ear, in connection with each other. *b*, concha of the auricle. *m*, half section of the external auditory meatus, with its ceruminous glands; it leads from the concha to the membrana tympani. *d*, is one-half of this membrane, or the membrane of the drum of the ear, which divides the external from the middle ear. *t*, the cavity of the tympanum, or drum of the ear, containing three little ossicles; it is also called the middle ear. *e*, the Eustachian tube, which leads from the tympanum to the back of the pharynx. *i*, the mastoid cells, which also communicate with the tympanic cavity. *s*, the semicircular canals. *c*, the spiral walls of the cochlea; these two last-named parts, with the vestibule, form the internal ear or labyrinth; they are lodged and incased in the petrous portion of the temporal bone, *p*, *p*. *f*, the styloid process.

with hairs on its inner and concave surface, called the *tragus;* opposite to that is another eminence, the *antitragus*, and below this is the *lobule*. The framework of the auricle is composed of a firm elastic cartilage, having nearly the same shape and varieties of surface as the perfect auricle, but it does not extend into the lobule. It is connected with the neighboring parts by ligaments, and is provided with three feeble muscles, named the attollens, attrahens, and retrahens auris. The skin covering the auricle contains sebaceous glands; these are most numerous in the concha. The external auditory meatus, *m*, is a slightly curved tube, extending from the concha inwards to a membranous partition named the *membrana tympani*, *d*, which completely closes it at the bottom; it measures about 1¼ inch in length, and is narrowest in the middle part. The outer half of the meatus has cartilaginous, and the inner half, bony walls; the former is continuous with the cartilage of the auricle. The skin lining the meatus is very thin, especially towards the bottom of the canal, where it is prolonged over the membrane of the tympanum, forming its outer layer; in the cartilaginous part, it is provided with fine hairs, sebaceous glands, and numerous ceruminous glands; the latter secrete the *cerumen* or *earwax*.

The middle ear, or *tympanum*, *t*, is a small cavity, or chamber, in the temporal bone, containing air, and certain small bones, named the *ossicles* of the ear, and a few muscles and nerves; it is placed between the membrana tympani and the outer wall of the labyrinth. Its outer boundary is formed by the *membrana tympani, d;* this is a thin semi-transparent membrane, of an oval shape, which slopes from above, downwards and inwards, and from behind, forwards and inwards, and is fixed by its circumference to a slight groove in the bone. It is the resemblance of this membrane to the head of a *drum* that has given the name of *drum* of the ear, or tympanum, to the middle ear. This membrane is composed of three layers; an outer one, which is an extension of the skin lining the external meatus, an inner layer, similarly derived from the mucous membrane lining the tympanum, and an intermediate layer, consisting of fibrous and elastic tissue, in which are bloodvessels and nerves: the middle layer is said to consist of two laminæ, the outer of which is composed of radiating, and the inner of annular fibres. (Toynbee.) The inner wall of the tympanic cavity corresponds with the outer surface of the labyrinth. The tympanum communicates, behind and above, with cells in the mastoid process of the temporal bone, called the *mastoid cells, i;* in front and below, it opens into the *Eustachian tube. e*, a trumpet-shaped canal, partly osseous, partly cartilaginous, leading into the upper part of the pharynx. There are also several small apertures, for the passage of vessels, nerves, and minute muscles.

The little bones, or *ossicles* of the ear, the smallest in the body, are three in number; they are stretched across the tympanic cavity, from the membrana tympani to the inner wall of that chamber, Fig. 74, and are named the *malleus*, the *incus*, and the *stapes*. The *malleus*, Fig. 75 *a*, 76 *a*, or *hammer-like* bone, is attached, by a somewhat twisted

Fig. 75.

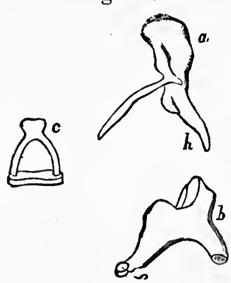


Fig. 75. The three ossicles of the ear, found in the cavity of the tympanum (magnified). (Arnold.) *a*, malleus, or hammer, its head; *h*, handle of the malleus; the other process is the processus gracilis. *b*, the incus, or anvil, consisting of a body and two processes, to the longer one of which, or long leg, is affixed the tubercle or orbicular bone, *o*. *c*, the stapes or stirrup bone, consisting of head, bars, and foot-piece or base.

process, called its *handle, h*, to the inner surface of the membrana tympani, near its centre; this attachment of the bone causes the membrane to be drawn in, as it were, towards the tympanum. Another long and very delicate process, called the *processus gracilis*, descends to the floor of the tympanum; while its rounded part, or *head*, which is also somewhat fixed to the roof of that cavity, is articulated with a concave surface, Figs. 75, 76, on the thick part of the incus. The *incus*, or *anvil-like* bone, *b*, consists of a massive part or body, and of two processes, or legs, being shaped somewhat like a double tooth. Besides being articulated with the malleus, the incus is attached, by its shorter leg, to the hinder wall of the tympanum; by its long leg, it is articulated with the third ossicle or stapes, which is the innermost of the three bones, by a little tubercle named the *orbicular* bone, *o*, which is sometimes regarded as a separate bone. The *stapes*, Figs. 75, 76, *c*, so named from its remarkable resemblance to a stirrup, is placed horizontally, and is attached, by its foot-piece or base, to the inner wall of the tympanum, where it is fixed, by fibrous membrane,

Fig. 76.

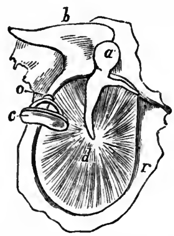


Fig 76. The membrana tympani, seen from the inner side, with the ossicles of the ear attached. *d*, the membrana tympani, set in the tympanic ring, *r*, of the temporal bone. *a*, the malleus, its long process or handle attached to the inner side of the membrana tympani, its slender process fixed in a recess in the wall of the tympanum, its head connected with the next ossicle. *b*, the second ossicle, or incus, its body joined with the malleus, its short leg standing out towards the side of the tympanum, and its long leg reaching to the third ossicle, to which it is fixed by a little tubercle, *o*, sometimes named the orbicular bone. *c*, the third ossicle or stapes, placed horizontally, with its base, in the natural condition, turned in the direction of the inner wall of the tympanum.

to the margin of an oval aperture in the bone, called the *fenestra ovalis*, leading into the labyrinth; it is so attached, as to be able to undergo certain movements. The foot-hole in this diminutive stirrup, is closed by a membrane, in its perfect state. These little bones, which weigh only a few grains, are covered with periosteum, supplied with bloodvessels, articulated together by perfectly movable joints, and provided with minute muscles, which, acting on the small levers formed by this jointed rod, influence the condition of the membrana tympani on the one hand, and of the fibrous membrane uniting the base of the stapes to the margin of the fenestra ovalis, on the other. The conjoined bones rotate upon a horizontal axis, passing through the slender process of the malleus, the head of that bone, and the body and short process of the incus.

The *muscles of the tympanum* are, like the bones, three in number. Two of these, the *tensor tympani*, and the so-called *laxator tympani*, arise from definite points of the surrounding petrous bone, and are inserted into the malleus; the first named is undoubtedly muscular, and draws the membrana tympani inwards, and tightens it; the latter was formerly described as a muscle having the opposite action, but it is either seldom present, or, as maintained by some authorities, is merely a reddish ligamentous structure. The tensor tympani muscle, according to Toynbee, is inclosed in a tubular ligament, which, he supposed, keeps the tympanum in a state of medium tension, the tensor tympani only being called into play when the tension of the membrane is increased. When the tensor tympani acts, the head of the long leg of the incus is drawn inwards, so that the base of the stapes, which is articulated with it, must also advance towards the inner wall of the tympanum, and so press in the membrane of the fenestra ovalis. Fick has proved this, by direct observation. The third muscle, called the *stapedius*, is inserted into the stapes; it is generally regarded as a tensor of the membrane of the fenestra ovalis, but, by some, it has been described as relaxing that membrane. It is the smallest muscle in the body. The tensor tympani is supplied by a nerve from the otic ganglion, the laxator, it is said, by the chorda tympani nerve, and the stapedius by a branch of the facial nerve.

Below and rather behind the fenestra ovalis, on the inner wall of the tympanum, is another small rounded opening in the bone, called the *fenestra rotunda;* it is closed in the recent state, by a membrane.

The mucous membrane lining the tympanum is thin, and, for the most part, covered with ciliated epithelium; it assists in closing the two fenestræ, and serves to form the inner layer of the membrana tympani. In the latter situation it is said to be destitute of cilia; lastly, it is reflected over the little ossicles, and the tendons of their muscles, and also over the chorda tympani nerve, which traverses the tympanum. It contains no mucous glands, but is constantly moistened with a yellowish fluid. In front, it is continuous with the ciliated mucous membrane lining the Eustachian tube, and, through it, with that of the upper part of the pharynx; behind, it enters and lines the mastoid cells.

The *internal ear*, or *labyrinth*, Fig. 74, *s*, *c*, and Fig. 77, so called from its complicated communications, contains the essential parts of the organ of hearing, viz., the membranous labyrinth and the cochlea. It consists of certain complex chambers and canals, each inclosing membranous and fluid contents; it is buried in the substance of the petrous portion of the temporal bone, and communicates, but by closed apertures, externally, with the middle ear, through the fenestra ovalis and fenestra rotunda, and internally, with the internal auditory meatus, which transmits the auditory nerve. The labyrinth consists of three parts, named, respectively, the *vestibule*, the *semicircular canals*, *s*, and the *cochlea*, *c*.

The *vestibule*, see Fig. 77, the central chamber of the bony labyrinth, is of an oval shape, corresponds in position with the fenestra ovalis and the base of the stapes, and communicates freely with the semi-circular canals and the cochlea. It is the fundamental portion of the labyrinth, and is the only part present in the lowest Vertebrata.

The *semicircular canals*, *s*, are placed above and behind the vestibule; they are three in number, and are designated, according to their position, *vertical*, *horizontal*, and *oblique*. These canals are curved bony tubes, about $\frac{1}{20}$th of an inch in diameter, each having at one end a dilated part, twice as wide, called the *ampulla*. As two of these tubes join together at one end, the three communicate with the vestibule, by five openings.

The *cochlea*, Figs. 74, 77, *c*, is a little spiral canal, with bony walls, resembling a small snail's shell, whence its name; it is placed in front

Fig. 77.

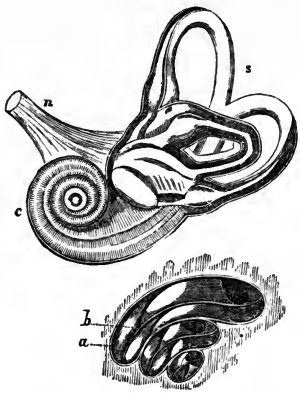


Fig. 77. Plan of the labyrinth or internal ear, showing its cavity laid open; enlarged. *n*, the auditory nerve, entering the labyrinth from the cavity of the cranium, *s*, the bony semicircular canals laid open, showing the membranous canals within them, and their ampullæ or enlargements; also the membranous vestibule and saccule, lying in the central portion of the osseous labyrinth named the vestibule. Leading from this is the spiral coil of the cochlea, *c*, also laid open, so as to show the striated surface of its lamina spiralis.

The lower figure shows a section through the cochlea, from base to apex. *a*, is the bony wall of the spiral tube, and *b*, the spiral partition, which divides each spire into two canals, named the scalæ, the upper one here being, throughout, the scala tympani, and the lower one, the scala vestibuli. (Arnold.)

of the vestibule, forming the anterior part of the labyrinth, and measures from base to apex about $\frac{1}{4}$th of an inch. It possesses a bony axis, called the *modiolus*, formed, as it were, by the coalescence of its spiral turns. A thin spiral bony plate, the *lamina spiralis*, projects from the sides of the modiolus; this plate, which turns round the modiolus, like the thread of a gimlet, gives attachment, in the recent state, to a double membrane, which contains some remarkable structures, to be presently described, and which is extended across to the outer wall of the spiral canal, Fig. 77, *a*. The partly bony and partly membranous spiral plate, *b*, which gradually narrows from the base to the apex of the cochlea, divides the turns of this canal, internally, into two semi-cylindrical spiral canals, named the *scalæ*. One of these, at the base of the cochlea, opens freely into the vestibule, and hence is named the *vestibular scala*. The other, the *tympanic scala*, ends at the fenestra rotunda of the tympanum. The two scalæ, moreover, *communicate* at the summit or *cupola* of the cochlea, by an opening in the membranous part of the spiral septum, named the *helicotrema*.

Within the vestibule and semicircular canals are certain membranous *sacs* and *canals*, which constitute what is named the *membranous labyrinth*. In the vestibule are two sacs, a smaller one, globular in form, the *saccule*, lying near the entrance into the cochlea, and a larger one, of an oblong form, called the *common sinus* or *utricle*, placed near the openings of the semicircular canals. In the interior of the semicircular canals, are three *membranous semicircular canals;* they are of the same form as the bony canals in which they are inclosed, having their respective ampullæ, and opening into the utricle by five orifices.

The walls of the membranous labyrinth, are firm and semi-transparent: they consist of three layers; the outer one is a loose vascular structure, containing pigment cells; the inner one consists of polygonal epithelial cells; the intermediate layer is a thick glassy-looking fibrous tunic. The saccule, utricle, and membranous canals, contain a limpid, slightly albuminous fluid, called the *endolymph.* Within the walls of the saccule and utricle, are two roundish clusters of solid imperfectly crystalline particles of mixed carbonate and phosphate of lime, called *otoliths* or *otoconia*, that is, *ear-stones* or *ear-sand;* the otoliths are connected with the fine ends of the vestibular branch of the auditory nerve, to be presently described. In the membranous canals and ampullæ, a few scattered particles of the same calcareous matter, are also found. The otoconia, or ear-sand, is wanting in some persons.

The interval between the inner walls of the osseous labyrinth and its membranous sacs and semicircular canals, as well as the scala of the cochlea, in which there are no membranous sacs or canals, is occupied by a thin, slightly albuminous fluid, called the *perilymph* or *liquor Cotunnii;* it resembles in composition, the endolymph just named, and is secreted by a delicate fibro-serous membrane, which lines all the inner surface of the osseous labyrinth; it supports the sacs, the canals, and the nerves distributed to these parts.

The cochlea, moreover, presents certain peculiar microscopic structures, upon and within the membranous portion of its spiral partition. Thus, the bony part of the lamina spiralis, presents a grooved margin, the upper edge of which, viz., that corresponding with the scala vestibuli, supports a finely toothed membrane, named the *zona denticulata;* its lower edge being perforated for the passage of nerves, is called the *habenula perforata.* These margins of the lamina spiralis, moreover, give attachment, each to a fine layer of periosteum, the upper one of which, connected with the zona denticulata, and turned towards the vestibular scala, is named the *membrane of Corti;* the lower one, seen in the tympanic scala, is called the *basilar membrane.* These two membranes form the semi-transparent partition formerly known as the membranous part of the lamina spiralis. Between these two layers is a triangular space, smaller than either of the scalæ, and now named the *scala media* (Kölliker), which is the essential auditory portion of the cochlea, and probably contains fluid. In the scala media are found two sets of minute rod-like bodies, arranged parallel with each other, in a radiated position from the axis of the cochlea, named the *rods of Corti;* the rods of the two sets are inclined towards each other above, so as to form an angle, where they appear to be connected together by a fine membrane, the *membrana velamentosa;* when viewed from the surface of the membrane, the series of rods suggests a resemblance to the keys of a piano. Between the grooved margin of the lamina spiralis, and the first set of the *rods* of Corti, is a cavity, and between the second set and the external wall of the cochlea, is another cavity, each containing nucleated cells of large size, named the *cells of Claudius*. The zona denticulata becomes gradually narrower, from the base to the summit of the cochlea; and so, in fact, must, more or less, all the structures of the membranous part of the spiral lamina. The outer margin of the membranous part of the spiral partition of the cochlea, has been described by some, as being composed of involuntary muscular fibres, and has received the name of the cochlear muscle. But this is not generally admitted; its structure being regarded as of the nature of delicate periosteum.

The *auditory* or *acoustic* nerve, the portio mollis or soft portion of the seventh cranial nerve (p. 251), is the special nerve for the sense of hearing. In the petrous portion of the temporal bone within the cranium, is a short canal or passage, known as the *internal auditory meatus*, the bottom of which corresponds with the vestibule and the base of the cochlea, and is perforated by numerous small openings, whence it is named the cribriform plate. The auditory nerve, Fig. 77, *n*, enters this meatus, and there divides into two branches, named the cochlear and vestibular nerves, the funiculi of which pass through the minute openings in the bottom of the meatus, into the labyrinth. The nerves destined for the saccule, utricle, and membranous semi-circular canals, are gathered into five or six bundles, invested and supported by the lining membrane of the cavity. Two of these bundles pierce the walls of the saccule and utricle, at the situations of the otolithes; here the fibres spread out, some radiating on the inner surface of the walls of the cavities, others lying amongst the earthy particles, and ending in free points. The remainder of these bundles are distributed to the ampullæ of the membranous semicircular canals, within which they end in a manner not yet understood, certain fine hair-like processes, here visible, being possibly the ends of the nerves, or else a fine hair-like epithelium. The numerous filaments of the cochlear nerve, ascend along small canals running up the modiolus; they then diverge laterally, in regular succession, along other little channels formed in the bony part of the lamina spiralis, on the under surface of the margin of which, that is, in the tympanic scala, they form a plexus, which contains ganglionic nerve-cells. The branches from this plexus, pass through the habenula perforata of the bony lamina spiralis, to reach the scala media. The ultimate fine and free extremities of these nerves, are said, by Kölliker, to end in the fluid of the scala media, where they probably become connected with the rods of Corti; some are also supposed to pass amongst, or into, the cells of Claudius.

Sound and its Propagation.

Sound, as sound, has no existence in nature, and, indeed, cannot exist independently of a sense of hearing. When sound is generated, certain disturbances of state in elastic bodies occur, as the result of concussion, friction, or other evidences of force; these disturbances have been proved to be delicate undulations, capable of regular propagation in all directions. The presence of some *matter* to be thrown into vibration is indispensable; for sounds can neither be produced in, nor propagated through, a vacuum.

Sonorous vibrations may originate in solid, liquid, or aeriform bodies. Their propagation to the ear may take place through either of these media. The rate at which sound travels in air is about 1050 feet per second. In water it travels about 4 times, and in highly elastic solid bodies from 7 to 18 times, as rapidly as in air. Sounds are transmitted most readily from solids to solids. In passing from solids to water they undergo a certain loss, and from solids to air a much greater loss. From water to solids they pass easily; but from water to air and from air to water, with very great difficulty. In their passage from air to solids they undergo very considerable loss in their intensity. It will thus be seen that the principal impediments to transmission occur in the passage of vibrations to and from solids and air, and to and from water and air; but by the interposition of certain peculiar arrangements of solid materials, in the form of elastic membranes, these impediments are almost entirely overcome; for a tense and dry membrane is easily made to vibrate, by sonorous undulations in air, and can, in return, readily excite them in air; moist membranes, on the other hand, scarcely vibrate under these circumstances. A tense membrane, however, placed between water and air, facilitates very considerably the passage of sonorous undulations in either direction. The transmission of the sound-waves, in both cases, is rendered easier, when some perfectly solid body is combined with the membrane, though still it is less easy than the transmission of sonorous undulations from water to solids, or from solids to water. The physical action of such membranes is of great importance in reference to the passage of sonorous vibrations through the acoustic apparatus of the ear. Membranes, whether tight or loose, conduct sounds in water without loss. In their passage from solids to water, sonorous undulations seem to reinforce the undulations in the water itself; this is more particularly the case in the vicinity of the solids.

In being propagated through the air or other medium, sounds lose their intensity, according to the distance through which they travel. From their source they are propagated equally in all directions; and therefore, like light, they diminish in force or intensity, according to the square of the distance. Thus, sounds heard at 2, 3, or 4 times a certain distance, are diminished in intensity in the ratio of 4, 9, or 16.

When atmospheric sound-waves meet with the surface of any opposing body, they are in part returned or *reflected* from it; the angle at which the reflection takes place is equal to the angle at which the sound-waves strike the surface, *i. e.*, the angle of reflection is equal to the angle of incidence. The reflection is sometimes almost entirely complete, as happens when the opposing body is fixed, solid, and very rigid. Sounds are reflected in water as well as in air. Some of the atmospheric sound-waves, instead of undergoing reflection, communicate to, or excite in, the opposing body, according to its elasticity or susceptibility, vibrations similar to their own.

The *communication* of sounds merely consists in the conveyance of sonorous vibrations from one body to another; such communication is common to both noises and definite tones. The *excitation* of sound by one body in another, is a different phenomenon, and occurs, in its purest forms, only with regular or definite tones. It is essential for this, that the natural note, emitted by the exciting and excited body, when struck or sounded, be identical. If two strings, *e. g.*, tuned to the same note, be placed side by side, and one be made to vibrate, the other is at once thrown into corresponding undulations, and gives forth the same note; this is called the *reciprocation* of sounds; the bodies are called *reciprocating*, and the sounds *reciprocal.* In the same manner, dry stretched membranes reciprocate their corresponding or natural notes. When a sounding body, instead of exciting its own fundamental note, in another body or in parts of it, excites other notes bearing certain harmonious relations to it, the latter body is said to *resound*, and is called a *resonant* body. This form of excitation of sound is not so pure as the one previously mentioned. The air itself is, in this sense, both a reciprocating and resonant body, more particularly when it is isolated in tubes, or is confined in closed chambers.

It has been stated by Helmholz that although certain sounds consist merely of a fundamental note produced by a single set of uniform vibrations, yet that most sounds are caused by combinations of the fundamental note with certain secondary or harmonic notes; and that the timbre or quality of sounds is dependent on the manner in which these secondary sounds are associated together in groups, named by Helmholz, *sound colors.*

Those sound-waves, the number of undulations of which corresponds or bears a certain definite numerical proportion to each other, are more or less agreeable to the ear, and are named *concords;* those which do not, are disagreeable when heard together or in succession, and are called *discords.*

Hearing.

In Man and air-breathing animals, sounds excited in the atmosphere reach the fluid of the labyrinth by two paths.—First, through the mixed membranous and osseous tympanic apparatus; and secondly, through the cranial bones. The passage of such sounds through the tympanum is effected readily, and with great range and delicacy of appreciation. Through the solid bones of the head, however, the transmission of sounds excited in the atmosphere is accomplished with difficulty; were it not so, the noises which would thus be produced would be unbearable; and they would, moreover, confuse the sounds received through the tympanum. It is through the bones of the head that sounds are transmitted to the internal ear, when, from any cause, the tympanum ceases to conduct sound. In speaking and singing, the hand placed on the head distinctly feels the vibrations of the cranial bones, and the auditory nerve is excited by them when the ears are closed.

Certain sounds produced by the concussion of solids against solids, reach the fluid of the labyrinth directly through the cranial bones; *e. g.*, the note of a tuning-fork held against the teeth or sides of the head, gives rise to sonorous vibrations, which are much more powerful than when transmitted to the ear through the air, and which can even be heard after its first sound has ceased to be distinguishable through the air. It is in this manner that sonorous vibrations are transmitted to the ear, when this is placed on the ground, and it is also of importance in hearing one's own voice. When the ears are closed, the sound of our voice transmitted through the cranial bones is powerful, but its tone is altered. The ticking of a watch heard when placed between the teeth, and the noise produced by striking the teeth together, are further examples of sounds conveyed through the cranial bones. The bones of the head also conduct sounds when these are transmitted to it through water, as in the case of divers. When the head is submerged and the ears are closed, the noise produced by the knocking together of two stones in the water, is very distinctly heard.

Such sounds as are produced by atmospheric undulations of sufficient power to affect the cranial walls, as, *e. g.*, the report of artillery and the sound of thunder, are transmitted to the internal ear, partly in a direct manner by the cranial bones, partly by the tympanum; for, though the ear be tightly closed such sounds are still audible. The external ear is, however, the proper inlet for almost all air-borne sonorous vibrations, and the tympanum is their proper path to the labyrinth. The particular use fulfilled by each part of the complex auditory apparatus in the conduction of sound-waves to the nerve of hearing, may now be considered.

The *pinna* or *auricle*, from its varied form, must receive and partly reflect the atmospheric sound-waves from and in many directions. Most of these undulations must be reflected externally; but the size of the auricle, its position, and external projection from the head, the direction of its general concavity, which is turned somewhat forwards, its dense, firm, structure, the tightness and smoothness of the skin investing it, and lastly, the form of the concha, and the relation of that recess to the external auditory canal, clearly indicate its office of collecting sound. The sonorous waves collected by the concha are reflected from it, so as to impinge upon the inner surface of the tragus, and are again reflected from the latter into the meatus. The auricle, moreover, conducts a certain number of sonorous undulations through its cartilaginous walls; this, perhaps, affords some explanation of the various and singular disposition of its surfaces, of its eminences and depressions, which are probably intended to meet the slighter sound-waves in such opposite and conflicting directions as to enable them to neutralize each other, so that those which are properly conveyed to the membrana tympani through the air of the meatus, may not be confused. This view is favored by the fact that the cartilage of the auricle has only one narrow point of connection with that of the meatus, and that it is cut up by many fissures, which partially separate its different portions. Some, however, suppose that the inequalities presented by the auricle are intended to receive at right angles, and therefore favorably for complete conduction, sonorous undulations from all directions.

The *external auditory meatus* receives and conducts sonorous vibrations to the membrana tympani. The impairment or loss of the power of hearing sounds which come through the air, caused by stopping the meatus with the finger, or by obstructing it with water, cotton-wool, or other substances, indicates its function as a conductor of sound. Owing to the curved direction of the canal, and to the partial concealment of its outer end, it is impossible for the atmospheric sound-waves to pass straight down from the exterior to the membrana tympani; they must undergo reflection many times, and at various angles, chiefly from the internal surface of the concha and of the tragus, down into the meatus, and from all sides of the latter, through the air within it, on to the tympanic membrane. The walls of the meatus, like those of the auricle, also conduct sounds; but their conducting power for atmospheric sound-waves is but feeble, and, in the ordinary condition, is probably specially provided against. If the meatus be closed externally with the tip of the finger, and the auricle or tragus be scratched, or if a watch be held against these parts, the sounds produced are extremely loud. Through resonance, the sounds, in fact, appear to be of increased intensity; for, the closed meatus constituting a resonant chamber, the resounding vibrations, excited in the air contained within it, act on the membrane of the tympanum, and, in this way, intensify the original sound. It is in a similar manner, that those sounds which pass through the teeth, or cranial bones, and which are known as head-sounds, are also rendered very much louder. The resonance of the mass of air contained within the meatus, also gives increased strength to the intensity of atmospheric sounds. If, indeed, a tube be added to the meatus, so as to lengthen the auditory passage, the intensity of all sounds becomes much greater.

The *membrana tympani* is admirably adapted for the reception of atmospheric sound-waves, and, although it may, to a certain extent, be thrown into vibrations through the osseous ring in which it is set, it is principally intended to be acted upon by the atmospheric undulations received through the auditory meatus. Its area is equal to about $\frac{1}{12}$th of a square inch. The slanting position of the membrane at the bottom of this canal, not only serves to increase its area, but is probably intended to adapt it for the reception of more numerous vibrations from the walls of the meatus, it may be, at some given angle, or in a perpendicular direction. In its usual condition, the membrane is in a state of moderate tension, due partly to its own structure, and partly to the support afforded it by the long process of the malleus. For a wide range of notes, its state of tension must be constantly undergoing variations; thus, for low sounds, it must be relaxed; for high sounds it must be rendered tense. If, *e. g.*, we close the mouth and nostrils, and force air into the tympanum, through the Eustachian tube, by means of an expiratory effort, or if we exhaust the air in the tympanic cavity, by an inspiratory effort, we increase the tension of the tympanic membrane; in this state, grave sounds are rendered less audible, or become altogether inaudible, whereas high ones are heard with greater distinctness.

The vibrations produced in the membrana tympani, are propagated chiefly, most readily, and, indeed, in a concentrated manner, through the tympanic *ossicles*, to the fluid of the labyrinth. The undulations of this membrane are communicated directly to the handle of the malleus, whence they pass to the head of this bone, are then propagated to the incus and stapes, and from the base of the latter bone, which, as already mentioned, is fixed by membrane into the fenestra ovalis, to the perilymph of the labyrinth. In performing this office, the chain of ossicles transmits the sonorous vibrations, communicated to them as a whole, and not vibrations resulting from motions in their particles. The direction of the undulations is unaffected by the angular arrangement of the ossicles; for the undulations are propagated, as they would be through a series of levers, from the stapes to the fenestra ovalis, in the same direction as that in which they are communicated to the handle of the malleus, viz.. in a perpendicular direction. It has been maintained by some, that the ossicles are merely employed as levers to regulate the tension of the three membranes of the tympanic cavity, *i. e.*, of the membrana tympani, of the membrane which, with the base of the stapes, closes the fenestra ovalis, and also through the medium of the perilymph in the cochlea, of the membrane closing the fenestra rotunda. The ossicles are, according to this view, not conductors of sonorous vibrations, which, it is supposed, are propagated solely through the air in the tympanic cavity, either to the membrane closing the fenestra rotunda, or else to the inner wall of the tympanum generally, and, in this manner, to the parts within the labyrinth. Sounds conducted through two such different paths as the ossicles and air of the tympanum, must interfere with, and confuse, each other, and hence it is probable, that they are conducted solely, either through the one or the other path. Considering the special connection of the ossicles with the expanded membrana tympani on the one hand, and with the chief aperture of the labyrinth on the other, their almost complete isolation in the atmosphere of the tympanum, and their greater conducting power, as compared with that of air, we must conclude that the little chain of ossicles is the actual path for the conveyance of sounds. In the tympanic cavity, on the contrary, we find contrivances apparently intended to impair the conducting power of the air within it; for this cavity communicates freely with the Eustachian tube and the mastoid cells; the inner surfaces of all these parts are moist, so that sonorous undulations, in whatever manner they may be excited within them, must be damped and deadened; moreover, the tympanic ossicles being invested by moist mucous tissue, are very bad conductors of vibrations to, or from, the air within the tympanum; so that, in this manner, they are secured against loss in one way, and interference in another. Again, the mucous lining of the tympanum is also especially adverse to the propagation of vibrations from the walls of the cavity, to the tympanic atmosphere, as well as to the reception of any such as, striking on its inner surface, might, if received upon a dry membrane, interfere with those which impinge upon its external boundary, or membrana tympani. Lastly, the fenestra rotunda, the supposed path of the vibrations propagated through the air in the tympanum, is, in comparison with the fenestra ovalis, small, retired in position, and has but a limited connection with the cavities of the labyrinth; in many animals endowed with a highly acute auditory sense, it is even placed in a neighboring cavity, which communicates with the tympanum through a very narrow fissure. It will thus be seen that, whilst the tympanic apparatus presents a combination of membranous and solid materials, well adapted for the conduction of sonorous vibrations, the tympanic cavity seems to possess contrivances specially calculated to impair the conducting properties of its contained air.

The membrana tympani is, moreover, a defensive structure, preventing the entry of foreign bodies into the tympanum; by it also the interior of this cavity is kept in a state of moisture. The interposition of the tympanic cavity between the outer and inner parts of the ear, serves, by the maintenance of warm air, at a uniform temperature, in that situation, to preserve the delicate structures of the labyrinth from exposure and changes of temperature, conditions essential for the performance of their functions.

By means of the *Eustachian tube*, which leads into the upper part of the pharynx, equal atmospheric pressure on the two sides of the membrana tympani, is maintained; the freedom of movement of the membrane, both in vibrating and in changing its degree of tension, is secured, and its undue tension, which would arise if either of its sides were subjected to excessive or deficient pressure, is prevented. Moreover, the existence of this outlet, protects the membrana tympani against the effects of external atmospheric shocks, and prevents accidental rupture or laceration. The Eustachian tube also serves as a conduit for the escape of the fluids secreted in the tympanum and mastoid cells; this is aided by the cilia covering its interior. The pharyngeal ends of those tubes are only open in swallowing and yawning; they can, moreover, be opened at will, by closing the mouth and nose, and then forcing air into them, or by performing the act of deglutition, when a clicking noise is heard, from the motion of the tympanic membrane and ossicles. The Eustachian tube is, however, always pervious in the healthy condition, and this is essential for the due performance of its functions; for when it is obstructed by accumulation of the fluids secreted by the parts, by the pressure of enlarged tonsils, by swelling of the mucous membrane at its orifice, or by any other cause, deafness, in proportion to the amount of obstruction, is produced. It was formerly supposed, that these tubes conduct one's own voice to the ears; this notion is, however, erroneous; the ticking of a watch introduced into the mouth, is but feebly heard; moreover, obstruction of the tubes does not render the hearing of one's own voice more difficult than that of other sounds.

The state of tension of the membrana tympani is regulated by the action of the muscles connected with the malleus and stapes. There can be no doubt that when the tensor tympani contracts, this membrane is drawn inwards, and that its tension is thereby increased. The action of the stapedius on the membrana tympani is doubtful; some regard it as also a tensor, but others as a laxator, of this membrane. But these two muscles must also influence the condition of the membrane which, with the base of the stapes, closes the foramen ovale. By Fick, the tensor tympani, acting indirectly on the stapes, is said to press inwards that bone; if so, it must tighten the membrane of the foramen ovale, and so increase the pressure, through the contents of the labyrinth, on the membrane of the fenestra rotunda of the cochlea. Concerning the action of the stapedius on this membrane, there is still, however, considerable doubt: some suppose that it must aid the tensor tympani in tightening, not only the membrana tympani, but also that of the foramen ovale; whilst others have conjectured, that it not only relaxes the membrane of the drum, but also draws outwards that of the oval foramen, and so diminishes the pressure, through the contents of the labyrinth, on the membrane of the fenestra rotunda.

In all the Vertebrate, and also in the aquatic non-Vertebrate animals, the sonorous undulations traverse a *fluid* medium, before they impinge on the extremities of the auditory nerve. In Man, and in the air-breathing Vertebrata, the undulations propagated from the tympanum, pass through the perilymph of the labyrinth, partly to the membranous utricle, saccule, and semicircular canals, so as to reach the nervous filaments contained in their interior, and partly along the scala vestibuli of the cochlea, pulsating over its denticulate zone, rods of Corti, and radiating nerves, up to its very summit, and thence, down the scala tympani, to the membrane of the fenestra rotunda. The exact use of the fenestra rotunda, and of the membrane closing it, is not well understood. As already mentioned, it has even been supposed by some, to receive vibrations directly from the air in the tympanum. But if, in hearing, the sonorous vibrations pass through the ossicles to the labyrinth, this membrane of the fenestra rotunda may either act as a spring, protecting the structures of the cochlea from too strong or sharp undulations, or it may prevent the return of those undulations backwards, along the scalæ of the cochlea. The weakness of the tympanic muscles, and the elasticity of the membranes which close in the labyrinth, are opposed to the idea, often entertained, of the occurrence of any great variation in the degree of tension of the fluid contents of the labyrinth. The changes above described are mainly effected through the increased, or diminished, pressure of the base of the stapes at the fenestra ovalis.

On the supposition that the tensor tympani and stapedius muscles *tighten* both the membrana tympani and the membranes of the foramen ovale and fenestra rotunda, and necessarily also the joints of the chain of ossicles between them, they must serve to protect the auditory nerve from too powerful vibrations, and, at the same time, render the auditory apparatus better adapted for the reception of high tones, and less fitted for the reception of low notes. These offices are probably regulated by reflex nervous action, and so may be compared with the functions of the iris, in regard to the regulation by it of the quantity of light which is admitted into the eye to act on the retina. But, on the supposition that the tensor tympani tightens both the membrane of the drum and the two membranes of the labyrinth, whilst the stapedius relaxes those three membranes, their reciprocal, but opposed, actions may be compared to those of the circular and radiating fibres of the iris, the former of which narrow, whilst the latter widen, the pupil, or aperture through which the light enters the eye. It is interesting to note, that these two little muscles of the ear are, like the circular and radiating fibres of the iris, supplied, the one by a cranial motor nerve, viz., the facial, and the other by a sympathetic branch, viz., from the otic ganglion, the two sets of the fibres of the iris being supplied, the former by the third pair, the latter by branches from the ophthalmic ganglion of the sympathetic.

Concerning the functions performed by the various parts of the *labyrinth*, nothing is positively known. The *fluid* contained in its chambers, serves to support the various membranes and nervous structures within it, in a certain degree of tension; and it is, as already stated, the last medium by which the sonorous vibrations are finally conveyed to the auditory nerve, the material particles of which must also be thrown into corresponding mechanical vibrations.

The *vestibule* is the part essential to the simplest exercise of the sense of hearing; for, even in the most rudimentary conditions, both of the human ear, and of that of the lowest Vertebrata, the vestibule, or the central chamber of the labyrinth, is the part first developed in connection with the recipient extremities of the auditory nerve. It is, in the lowest Fishes, the only part of the labyrinth which is present. Moreover, so long as it remains unimpaired, the sense of hearing in Man and the higher Vertebrata, is not lost, although all the external and tympanic portions of the ear be destroyed. From its position opposite to the base of the stapes, it must first receive the sonorous vibrations travelling by that path, and may serve to transmit them to the rest of the labyrinth.

The *cochlea* and its nerves must undoubtedly receive direct vibrations, *i. e.*, vibrations communicated through the bones of the cranium; for there exists an intimate connection between the lamina spiralis, on which the nerve tubules are distributed, and the osseous walls of the labyrinth, the two being continuous with each other. But the nerves distributed to the membranous part of the lamina spiralis of the cochlea, must also receive sonorous vibrations transmitted from the tympanic apparatus, either by the fenestra ovalis, or the fenestra rotunda, through the fluid of the cochlea and its special recipient and translating apparatus, which converts the mechanical into the nervous sonorous vibrations. It has been conjectured, that the lamina spiralis, with its highly complex, denticulate, rod-like, and nervous structures, is, on account of the graduated lengths of some, at least, of its component parts, connected with the reception of sounds of different *pitch*, the sonorous undulations of which are themselves of various lengths. The rods of Corti especially, have been supposed to act like vibrating elastic bars of different lengths, just as different sized tuning-forks vibrate in unison only with their own note, or with its harmonics. Another conjecture may be offered, namely, that in the complex apparatus of the cochlea, there may also exist contrivances for arresting the vibrations, after they have accomplished the due stimulation of the auditory nerve, in the same manner as the dampers of a piano stop the vibrations of the strings, so as to prevent the confusion of successive notes, thus performing, as it were, an office corresponding with that of the choroid coat in the eye, which absorbs the rays of light after they have acted on the retina, and thus prevents the confusion of successive images. The idea that the cochlea is an organ for distinguishing pitch, was suggested by Dugès, and considered by him to be supported by the general concurrence of the development of the cochlea with the relative extent of the vocal sounds, in the same class of animals, as may be understood by comparing the cochlea and the voice in Mammalia, Birds, and Reptiles. Helmholz further attributes to the graduated structures of the lamina spiralis of the cochlea, the office of receiving the impressions which produce the so-called *sound colors* already referred to, and so of aiding in the recognition, not only of the pitch, but of the *timbre* or quality of sounds. Each nervous filament is supposed to receive single vibrations; and the combinations of these in harmonic groups, with the fundamental notes, in the production of ordinary sounds, are recognized with greater or less facility, by different persons. There are individuals as unable to appreciate musical sounds, as others are to distinguish colors; whilst persons possessed of an acute musical ear, may be compared with those who are remarkable as colorists. Supposing that the cochlea may be the part through which we receive impressions concerning pitch and timbre, and so of melody and harmony, the membranous labyrinth may be the part which informs us of the intensity, quality, or loudness of sounds.

The *semicircular* canals, or rather, their contained membranous canals, assist in the reception of sounds from the cranial walls. They are also supposed to be specially concerned in distinguishing the *direction* of sounds. The relative position of these canals favors this idea; for in Man, and in almost all animals in which they exist, they occupy three planes nearly at right angles with each other, and therefore corresponding with the three dimensions of a cube.

[The semicircular canals, evidently intended to perfect the sense of hearing in man and the higher animals, are believed by Dr. Samuel Jackson, Emeritus Professor of the Institutes of Medicine in the University of Pennsylvania, to act by suppressing the sonorous undulations or vibrations of the lymph of the vestibule, which are the immediate excitants of the sense of hearing. They arrest the waves of reflexion, which would necessarily occur in a simple cavity, wholly limited by plane surfaces, as the vestibule would be without these appendages, and as is the case with the rudimentary vestibule or internal ear of the Invertebrata. The production of mere sound or noise of different intensities would result from reflected undulatory vibrations maintained in the labyrinthic fluid, while the perception of immense numbers of fine and delicate tones, and varying qualities of sound, now so characteristic of the hearing of man and the higher animals, would be rendered impossible in the confusion of vibrations to and fro in the fluid of the labyrinth, but for the semicircular canals, by which they are suppressed. These canals, in the apparatus of hearing, are considered by Dr. Jackson as corresponding, in function, with the pigmentum nigrum of the choroid coat in the organ of vision. The precise mode in which this suppression is accomplished, will be better appreciated by following up Dr. Jackson's comparison:

"The two senses and their apparatus are homologous. The essential phenomena and laws of each are identical. The knowledge of those of the one sense demonstrates those of the other. The conditions of perfect vision and perfect hearing are the same. They are, 1st, The existence of separate, independent, sensitive spaces or sections of the retina for distinct images and perceptions of visual impressions. Volkman estimates these to be 0.0005 mm.; and others at $\frac{1}{5000000}$ of an inch. 2d, A single distinct impression made by the molecular vibration of the ether—the excitor of the sense of sight.

"The above conditions are obtained (*a*) by the special anatomical arrangement of the retina; (*b*) by the refracting apparatus of the globe of the eye, that concentrates the undulatory rays of the ether, proceeding from every point of a visual object on the distinct, sensitive points or spaces of the retina; (*c*) by the suppression of the undulatory vibrations immediately they have excited an impression on the retina, by the black pigment of the choroid coat. Their reflection from the exterior surface of the sclerotic coat, and reiterated excitement of the retinal surfaces, is thus prevented. In Albinos the pigment of the choroid is either deficient or absent, and the consequence is indistinct vision in daylight, from the general excitement of the retina by the reflected undulations of the ether occupying the globe of the eye.

"The same conditions are obtained in hearing: 1st, By the auditive nerve being decomposed into its separate filaments and ganglionic vesicles, amounting to some thousands, and spread out in a manner to receive single, individual impressions in the membranous vestibule, ampullæ, and on the lamina spiralis of the cochlea. 2d, By the molecular undulations or vibrations excited in the fluids, peri- and endolymph, by the sonorous undulations communicated by the stapes, occupying the fenestra ovalis. From this point they radiate in expanding waves of undulations, strike on, and pass through the membranous vestibule and ampullæ, on which the filaments of the vestibular branch of the auditive nerve are arranged, producing a single, distinct impression, reinforced by the resonance of the superimposed otoconiæ, and exciting a single and distinct impulse and perception of sound. These bodies act like the sounding-board of the piano. The sonorous vibration having thus completed its office, the specific excitation of the sense of hearing must, like that of the visual vibration, cease, or be suppressed. This occurs, in part, in the ampullæ, but mostly in the semicircular canals.

"The vibrations of the endolymph, reaching the ampullæ, are partially broken and weakened at their openings: those entering the ampullæ again expand, losing thereby their impetus, and either die away against the membranous walls, or come in contact with the vibrations of the perilymph on their exterior. The two can scarcely be in perfect consonance of expansion or condensation, and interference ensues, by which they are suppressed. In this mode all the feebler vibrations are terminated. Those of greater force enter simultaneously the two opposite openings of the semicircular canals. The orifices and commencement of each canal differ as to size and form, and consequently each entering wave of undulatory vibration is modified, thus losing their consonance of expansion, and when they meet interference and suppression result. Reflection of sonorous vibrations is completely provided against.

"Parallel conditions exist in the cochlea. Its two canals—the superior scala vestibuli, and the inferior scala vestibuli—are filled with lymph fluid, continuous and identical with that of the vestibule. The first, the scala vestibuli, according to the latest investigations of Kölliker, is the principal seat of hearing. On its lamina spiralis is expanded a sentient, nervous structure, the recipient of the sonorous vibrations excitative of the sense of hearing. It is the homotype of the retina of the eye. The scala tympani furnishes space for spreading out the filaments of the nerve, but the terminal extremities pass through the membranous spiral lamina, to be incorporated with the sentient organ of hearing in the superior canal or scala vestibuli. The filaments of the inferior canal or scala tympani are mere conductors of the nervous excitement of the auditive sentient membrane. The scala tympani, similar to the semicircular canals, has no direct connection with the production of hearing. It is the homotype of the semicircular canals, and performs the same office.

"The sonorous vibrations, starting from the stapes and fenestra ovalis, rushing into the adjacent opening of the scala vestibuli, excite, by their impulse, the auditory membrane or retina, spread over its lamina spiralis, and reach its termination, where it opens into the scala tympani. Feeble vibrations may subside spontaneously by exhaustion from their extension. The stronger pass on into the scala tympani, where they fade away, or are suppressed by the interference of vibrations entering the inferior canal by the fenestra rotunda, from the tympanum. The condition for perfect hearing, for the distinct perception and appreciation of the finest tones and notes, so that each vibration shall make but one, single, distinct impression, and then be suppressed, is thus amply fulfilled.

"Analogous provisions are perceived to exist in the tympanum, to preserve in that cavity the perfect wave systems of undulations, indispensable to the perfection of the sense of hearing. Vibrations existing in air, contained in a cavity with plane walls, would continue to be reflected from side to side, producing confused sounds or noise. The air in the tympanum is thrown into vibrations by impulses of the membrani tympani. They are communicated, pure, and in perfect accord, to the membrane of the fenestra rotunda. This curious and beautiful result is effected in the following manner: on one side the tympanum communicates, by numerous openings, with the mastoid cells communicating with one another. All the vibrations impinging on this side are suppressed in the mastoid cells. Those that reach the opposite side are swallowed up and lost in the Eustachian tube. All resonance and reflection of vibrations are suppressed, and the wave systems of sonorous vibrations traverse the tympanum undisturbed, enter, with augmented force, the lymph fluid of the scala tympani, and meet the corresponding undulations coming from the scala vestibuli, from which both systems are suppressed by interference.

* * * * * * *

"The small space through which the vibrations pass, and the rapidity of their movements in fluids, cause the impressions they make on the nervous sentient organ, and the perceptions they excite, to appear as an instantaneous act. The mind has cognizance of them, however diversified they may be, as a unity of sounds simultaneously instant in action; whence it forms the compound idea of perfect harmony.

"An analogous phenomenon occurs in vision. When a body, composed of different forms and colors, is presented to the eye—as a bouquet of flowers, a landscape, or picture—each different form, color, tint, and shading, are perceived blended, but perfect and distinct, forming the image of a single object. Yet thousands of ether vibrations are traversing the eye, and are exciting each a separate, distinct impression, without confusion, on the retina, and as many distinct and separate perceptions, from which a corresponding compound idea of a single object is formed by the mind." F. G. S.]

The *otoliths*, or otoconia, when present, are supposed to intensify the sonorous undulations, at or near the fine extremities of the auditory nerves of the vestibule, saccule, and ampullæ of the semicircular canals.

The sense of hearing varies much, as regards acuteness, in different persons; so also does the power of distinguishing differences in pitch. The power of judging of the direction of sounds, would seem to be almost wholly the result of habit. The different intensity of a given sound, as heard by the two ears, may assist in the determination of a knowledge of its direction; but, to a certain extent, one ear will suffice for this purpose. The notion of the distance of sounding bodies is also acquired by habit, the mind chiefly judging from the relative loudness or faintness of a known kind of sound; but, in this respect, there is great liability to deception, and hearing is not so accurate a guide as sight. Like the other senses, hearing can be much improved by education; in the blind, it is so highly developed, that they are mainly, if not entirely guided by it, in walking. The Indian by listening on the ground, can detect the distant footfall of his enemy or prey.

The auditory nerves can be excited by various internal mechanical causes, operating generally through certain movements of the blood and bloodvessels; for example, in dilatation of the vessels from congestion of the head, in extravasation of blood, in morbid conditions of the circulation in the brain and internal ear, dependent on extreme debility, in narcotic poisoning, and in great bodily collapse, as before the commencement of fainting. Obstructions in the tympanum or Eustachian tube may also produce abnormal noises in the head. It is not yet determined whether electricity can excite the auditory sense, unless indirectly, by disturbance of the tympanic apparatus.

Sonorous undulations conducted through the tympanum are referred by the sensorium to the exterior; whereas those conducted through the cranial bones appear to proceed from the head itself.

As in the other organs of sense, here also there are after-sensations and subjective sensations. For example, the noises in the ear which remain after certain sounds, when these have excited the auditory nerve for a lengthened period, are analogous with the after-sensations of touch, taste, and smell. The noises in the head and ear, such as musical phrases, and the singing, buzzing, ticking, and humming sounds heard by persons suffering from disease of the brain or auditory nerve, are examples of subjective sensations. Delusions of the auditory sense are not uncommon, especially amongst excitable persons.

The various uses of the sense of hearing are sufficiently obvious.

The Organs and Sense of Hearing in Animals.

The organ of Hearing, in Mammalia generally, is, in all particulars, constructed on the same plan as that of Man. The external ear consists of a cartilaginous pinna, and of a partly cartilaginous and partly osseous meatus. The former is often large, and provided with numerous powerful muscles; in the beaver, otter, and other diving animals it is but slightly developed; in the seals, the mole, the Cetacea, the armadillo, and the ornithorhynchus, it is absent. The external meatus is sometimes provided with a fold of the auricle, by means of which it can be closed, as the ear-flap of the elephant and the valve-like antitragus of the water-shrew. The general development of the external ear appears to be proportional to the acuteness of hearing. It attains its highest development in the bats, in which its forms are often remarkable. The entrance to the tympanum is usually surrounded by a separate bone, the os tympanicum; but in the monkey, as in man, this is blended with the petrous part of the temporal bone. The cavity of the tympanum frequently extends widely into the adjacent osseous structures. The tympanic ossicles are three in number; they present great variety of shape, although they always resemble those of man. In some marsupials, the stapes is simply style-shaped with a broad base, or is divided into two short crura only, a condition which somewhat approaches the representative bone, the columella, in birds. In the Cetacea the walls of the tympanum are very thick, and when detached from the rest of the petrous bone, form the remarkable so-called ear-bone of those animals; in them the Eustachian tube is membranous. In different species of Mammalia, the cochlea forms from 1½ to 5 turns. The labyrinth is completely embedded in the petrous portion of the temporal bone; in the mole, however, the vertical semicircular canals project into the cavity of the skull. In some Mammalia, no otoliths, nor even otoconia are present.

In Birds the external meatus is present; there is, however, no pinna, but only a radiated arrangement of the feathers, or a few flaps of skin around the aperture; these are very large in the owl tribe. Otherwise, the organ of hearing is highly developed. The membrana tympani is oval, and projects externally, instead of sinking inwards as in Mammalia. The tympanum communicates with the mouth by a very large Eustachian tube, and also, by different foramina, with air cells in the cranial bones; these cells are very capacious, and generally even extend across the middle line, so that the two tympanic cavities are connected with each other. There is only one tympanic bone, a modified stapes, here named the columella, which is joined by two or three cartilaginous processes, representing the other bones, to the membrana tympani, and rests, by its other extremity, upon the foramen ovale. The tensor tympani is the only muscle present. The three semicircular canals are of large size, in proportion to the cranium; the vestibule is small. The cochlea is not convoluted, but forms a slightly curved, conical canal; in its interior are two slightly twisted cartilaginous folds, which represent the spiral lamina of the Mammalia.

Reptiles, generally, are unprovided with an external ear, the crocodile alone possessing a rudimentary pinna, in the form of two folds of skin, the upper one of which incloses a plate of cartilage and possesses a muscular valve. All reptiles except serpents, possess a membrana tympani, tympanic cavity, and Eustachian tube. In the serpents, however, these parts are absent, and the columella, which is represented by a small rod-like bone, is embedded in the flesh. In some, the membrana tympani is visible externally; in others, it is covered by the skin. The columella consists of a row of little bones; the first, corresponding to the stapes, closes in the fenestra ovalis; the second represents the incus; and the third, a cartilaginous portion connected with the membrana tympani, the malleus. The labyrinth contains a rudimentary cochlea, consisting of a short, conical, straight, or slightly curved canal, divided by an internal septum into two scalæ. This simple form of cochlea illustrates very well the formation and structure of the more complex spiral cochlea in the Mammalia and Man; for by imagining such a double conical tube or canal to be rolled upon a central axis, the shell-like organ of the higher Vertebrata would be produced. There are three semicircular canals provided with ampullæ. The sac of the vestibule contains otoliths, which form a friable mass.

In Amphibia, the cochlea is absent, and there is no fenestra rotunda. Some possess a tympanum, others do not. The triton has merely a vestibule with a single otolith and three semicircular canals; the vestibule approaches the exterior by the fenestra ovalis, which is not occupied by the stapes, but is closed by a small lid. The flat plate of the stapes alone represents the auditory ossicles; it lies in the muscles. In the fully developed frogs, with but few exceptions, there is a membrana tympani, and a tympanum, from which a short Eustachian tube passes into the throat. The pipa has a cartilaginous membrana tympani, and its two Eustachian tubes open, by a common orifice, in the middle of the palate. The walls of the labyrinth are partly cartilaginous, partly bony, and this cavity ends externally in the fenestra ovalis, from which three ossicles, in part cartilaginous, pass across the tympanum to the membrana tympani.

In Fishes generally, the external ear and tympanum never exist. The cochlea also is absent, so that even the internal ear is incomplete. Some osseous fishes, however, present rudiments of a tympanic cavity. The vestibule always contains a utricle, and generally a saccule as well, each with its included otolith; connected with these, are either some imperfectly developed semicircular canals, or one, two, or more commonly, three perfect canals of large size, ending in the vestibule. In certain cartilaginous fishes, viz., the rays and skates, the cavity of the vestibule is prolonged to the surface of the back part of the head, where a membrane, which may be said to correspond with that closing the fenestra ovalis, is seen. The walls of the vestibule and semicircular canals, which are either cartilaginous or bony, according to the character of the skeleton, usually project into the cranial cavity; in the higher forms only are they partly contained in the temporal bone. No auditory organ has yet been discovered in the amphioxus.

From the preceding account it will be seen, that a fully developed spiral cochlea exists only in the Mammalia; that this part is comparatively simple and slightly curved in Birds, is quite rudimentary in Reptiles, or altogether absent, as in the aquatic chelonia, and is wanting in Amphibia and Fishes. The tympanic chamber and apparatus, together with the Eustachian tube, are also simplified in Birds and Reptiles, below which a tympanum does not exist, except in the most highly developed amphibia, in which a small tympanum is present, but there is no fenestra rotunda. The above-named structures, including also the fenestra ovalis and fenestra rotunda, are therefore proper to animals which live entirely *in air*. This general fact must be regarded as a proof of the special office of these parts, as conductors of atmospheric sounds. In those which inhabit water exclusively, the semicircular canals and vestibule alone are present, and even the former disappear in the lowest organized fishes, leaving the vestibule only as the representative of the auditory organ. In such cases, the sonorous vibrations must reach the labyrinth directly, through the framework of the head. The otoliths are more largely developed in the simpler forms of auditory apparatus.

In such of the non-vertebrated animals as are purely aquatic, the auditory apparatus consists essentially of a sac or vestibule, in which a more or less regularly formed cretaceous otolith is found, and which is connected with a special nerve. Into this sac, the sonorous undulations are readily conveyed from the water; it is analogous to the membranous vestibule of the vertebrate ear. In the air-breathing Annulosa, other contrivances, of which dry elastic membranes, calculated to receive vibrations through the air, form a part, are met with.

In the Mollusca, double symmetrical organs of hearing are present in all the classes, even in certain Lamellibranchiata. They are connected by means of short auditory nerves, either with the subœsophageal ganglia, as in the higher Mollusca, or with the pedal ganglia, as in the Gasteropodous and lower forms. In the Cephalopoda, these organs consist of two flask-shaped *sacs*, the analogues of the membranous labyrinth of the Vertebrata. They lie close together in an excavation of the cartilage of the head, the cartilaginous vestibule. Each contains a large cretaceous otolith, with some fluid. The space between the sac and the cavity in which it is lodged is filled with gelatinous fluid, and the cavity itself is perforated by the auditory nerve, which is distributed to the sac. In the remaining classes of the Mollusca, the organs of hearing are more simple, each consisting of a simple roundish or oval sac, situated in the soft parts, closely attached to the auditory nerve, and containing a fluid, with a central otolith suspended in it; sometimes the sac is lined with a ciliated epithelium. Amongst the Molluscoida, similar auditory vesicles are found in some Ascidioida.

The Annulosa are not universally provided with acoustic organs. In Insects, it has been conjectured, that such organs exist at the base of the antennæ, where a soft membrane, made tense by those parts, is supposed to represent a sort of tympanic membrane; others imagine that the antennæ themselves, being supplied with large nerves, can appreciate vibrations. In the grasshopper and cricket tribes, there is sometimes found, on both sides of the first abdominal ring, a large oblong depression, set in a firm horny ring, and closed at the bottom by a delicate membrane. A little vesicle, containing a watery fluid, is connected with the inner surface of this membrane, by means of two horny processes; this may be regarded as a sort of rudimentary labyrinth. The auditory nerve, which proceeds from the third thoracic ganglion, forms a swelling as it spreads over the vesicle, which is, by some, regarded merely as a portion of the nerve. A large tracheal sac, near the auditory sac, connected with the third stigma, may perform the office of a tympanum. In certain locusts, the organ of hearing is still more curiously placed, viz., on the chief segment of the front limbs; it consists also of a vibrating or tympanic membrane, sometimes superficial, sometimes embedded in a cavity, having a slit-like aperture; near it is found a tracheal chamber, and the nerve spreads out upon it, in the form of fine parallel striæ. In the Myriapoda, organs of hearing have not yet been found. The Arachnida appear to possess considerable auditory sense, but no special organ of hearing has been discovered in them. Amongst the larger Crustacea, the organ of hearing is now said to be usually situated in the basal joint of the first pair of antennæ. In this situation, for example, in the lobster and river crawfish, there exists a hollow chamber opening externally by a narrow slit in its thin membranous walls, and occupied by a sac filled with water, in which are frequently found minute particles of sand, which have entered from without. On one side of this chamber is a fine striated structure; a nerve which arises with the nerve of the antennæ, from the subœsophageal ganglion, spreads out upon it. A greenish glandular mass, found near this sac, is analogous to the cement gland in the cirrhopods, which are, however, destitute of auditory sacs. The acoustic function of this antennal sac has been doubted, because its small tympanum-like covering membrane seems less adapted to convey vibrations than the firm shell of the animal; moreover, since in some species it exhibits an opening which permits of the entrance of water into its interior, it has been described as an olfactory organ. (Rosenthal.) This organ presents great varieties among the decapoda; in the spiny crab its covering is crustaceous, and little muscular bundles are found beneath it. In the squilla it is altogether wanting; but in them, in certain species, there is found in the base of the second and seventh thoracic pairs of feet, and in mysis, in the inner pair of the tail-plates, a completely *closed* sac, containing a spherical crystalline body, provided with stiff bristles, which has been regarded as an auditory organ, analogous in its formation with the simple auditory vesicles of the lower Mollusca. In the Annelida or worms, a pair of ciliated auditory vesicles, with contained otoliths, is often present in the head; they are connected with the œsophageal ring. The great variability in the seat of the auditory apparatus is accordingly quite as marked in the Annulosa as in the Mollusca, as is exemplified especially in the grasshopper, locust, mysis, and squilla, in which, as in the Gasteropodous and Lamellibranchiate Mollusca, it is associated with the pedal or locomotive ganglia, or even with some part of the locomotive apparatus. In the Vertebrata, likewise, the organs of hearing are connected with the back of the medulla oblongata, lower than the centres of origin of the nerves of the other special senses, and nearer, therefore, to the motor apparatus generally.

Amongst certain of the Annuloida, as in the marine Turbellaria, and perhaps also in some Rotifera, an auditory vesicle, containing an otolith, and no longer double and symmetrical, but single, is found lying closely on the chief nervous ganglion. But most of the Rotifera, and all the Entozoa, are destitute of special auditory organs; nor has any such apparatus been detected in the Echinodermata.

In the Cœlenterata, however, there are found, in both the discoid and ctenophorous forms, but chiefly in the medusæ, auditory sacs named *lythocysts*, which inclose crystalline particles, supposed to be analogous to otoliths; these are numerous, and are found on the margin of the disc; they frequently have pigment spots, or ocular spots, near them.

The Protozoa are entirely destitute of auditory organs.

THE SENSE OF SIGHT.

The Organs of Sight.

The *organs of sight*, in Man, consist of the *eyeballs* or *globes* of the *eyes*. The external protective *appendages of the eye*, are the *eyebrows*, the *eyelids*, and the *lachrymal gland* and *apparatus*. The eyeballs and the lachrymal glands, are lodged in the bony cavities, named the *orbits*.

The *orbits* are pyramidal in shape; their apices are directed backwards and inwards, so that their axes converge posteriorly, and diverge anteriorly. In the apex of each orbit, are several openings, which transmit the optic nerve, the common sensory, motor, and sympathetic, nerves of the eyeball, as well as its bloodvessels and lymphatics. The orbit also contains the lachrymal gland, the *ocular muscles*, and a quantity of fat, on which the eyeball rests and moves as upon a soft cushion; between this and the eyeball, is a loose cellular capsule.

The *eyebrows*, or the arched eminences surmounting the orbits, consist of thick musculo-cutaneous ridges, inclosing some fat, and studded with hairs set obliquely outwards.

The *eyelids*, or *palpebræ*, are the two thin movable *covers* of the eyeball, the free margins of which are bevelled, and beset with the *eyelashes*. The upper one is larger and more movable than the lower one, and is provided with a special muscle, named the *levator palpe-*

bræ. Each eyelid consists of a thin semilunar plate of soft fibro-cartilage, the *tarsal cartilage*, which gives it form and support; outside this cartilage, is a thin, delicate, and very loose skin, destitute of fat, and a few pale striated muscular fibres, belonging to the so-called *orbicularis* muscle, together with some non-striated muscular fibres, which are more numerous in the lower lid (H. Müller); on its inner surface, it is lined with mucous membrane. The cartilage of the upper lid is larger and thicker than that of the lower lid, which forms merely a narrow plate. The cartilages are connected at their orbital or attached margins, with the periosteum of the circumference of the orbit, by broad membranes called the *fibrous membranes* of the lids. At the outer angles, these membranes are strengthened, and tie the outer ends of the cartilages to the bone; the inner ends of the cartilages are connected with a short, strong, horizontal tendon, called the *tendon of the eyelids*, or *tendo oculi*, which extends from the tips of the cartilages, to the inner wall of the orbit. The cartilages are kept in contact with the eyeball, in all its various movements, by means of a small muscle, named the *tensor tarsi*, placed behind the tendon of the eyelids.

The *levator palpebræ* muscle, above mentioned, arises from the bottom of the orbit, and passes forwards above the eyeball, to be inserted into the posterior edge and surface of the upper tarsal cartilage; it pulls back this lid, and so uncovers the front of the eyeball. The lower lid has no depressor muscle to lower it, but descends a little by its own elasticity. According to Wagner, the unstriped muscular fibres of the lids, also co-operate in opening the eyelids, being governed, as shown by experiment, by the sympathetic nerve. The ordinary closure of the eyelids is accomplished by the action of the part of the orbicularis muscle which lies upon the eyelids; their more forcible closure, by the part of the same muscle which surrounds the orbit. The levator palpebræ muscle is supplied by the third cranial nerve, and the orbicular muscle by the seventh or facial nerve.

The mucous membrane lining the inner surface of the eyelids, is continuous with the skin at the free margins of the lids; it is reflected from the lids, over the fore-part of the eyeball, so as to connect these two parts, whence it is called the *conjunctiva;* it is also prolonged into various ducts and canals. Where it covers the anterior transparent part of the eye, named the cornea, the conjunctiva is very thin, colorless, and but slightly endowed with sensibility; the part covering the white portion of the eyeball, called the sclerotic coat, is somewhat thicker. On the inner surface of the eyelids, it is much thicker, highly vascular, very sensitive, provided with closely-set papillæ, and firmly adherent to the cartilages. It is covered by a many-layered squamous epithelium.

On the ocular surface of the tarsal cartilages, between them and the conjunctiva, are situated the *Meibomian glands.* These are modified, and complex, sebaceous glands (Fig. 78), consisting of a series of ducts, placed side by side, and perpendicularly to the margins of the lids, each communicating with numerous lateral follicles or crypts, *b.* They occupy little grooves on the inner surfaces of the cartilages, and their ducts open, by minute orifices, *a*, on the free margins of the lids. Each duct, with its lateral crypts, resembling rows of onions on a string, consists of a membranous wall, lined with a glandular epithelium, which secretes a sebaceous matter. In the upper lid, there are about thirty glands; in the lower lid, from fifteen to twenty, and they are much shorter.

Fig. 78.

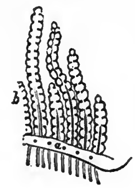


Fig. 78. A portion of the margin of the upper eyelid. showing a few of the Meibomian glands attached to it. *a*, orifices of the central ducts of each gland. *b*, rows of follicles or sacs, arranged upon each central duct.

The elliptical interval between the opened eyelids, is called the *palpebral fissure;* the outer and inner angles of this fissure, are named the *canthi.* At the outer canthus, the bevelled margins of the lids, form an acute angle; but at the inner canthus, the margins, which are here rounded, are separated by a small interval, called the *lacus lachrymalis*, the *lachrymal lake* or *pit*, Fig. 79. Along the margins

Fig. 79.

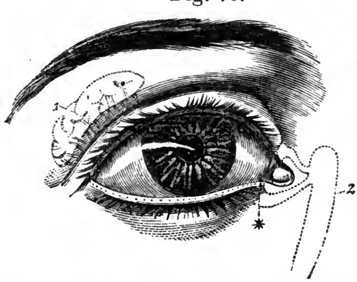


Fig. 79. Front of the eyeball and its appendages. 1, dotted outline, showing the position, size, and shape of the lachrymal gland. 2. similar outline. showing the form and position of the lachrymal sac and nasal duct. On the left hand of this, other dotted lines indicate the course of the two lachrymal canaliculi, leading into the sac, one above, and one below, the lachrymal lake or sinus, which is occupied by the caruncle; between the caruncle and the eyeball, is the edge of the rudimentary nictitating membrane. The asterisk * indicates the orifice of the lower canaliculus, named the inferior lachrymal punctum. The orifices of the Meibomian glands. are seen in the margin of the lower eyelid The white exposed part of the eyeball, corresponds with a portion of the sclerotic coat of the eye. The circular dark-colored part represents the iris, perforated by the pupil. and covered by the transparent coat or cornea.

of the eyelids, are two or more rows of finely-curved hairs, named the *cilia* or *eyelashes;* in the upper lid, they are more numerous, thicker, and longer than in the lower lid; the lashes of the upper lid curve upwards, those of the lower lid downwards, so that they do not interlace when they meet or separate. At the inner canthus is placed a soft red fleshy-looking eminence, the *caruncle*, from *caro*, flesh; it is made up of a cluster of follicles, covered with mucous membrane, and studded with a few very fine hairs. Between the caruncle and the eyeball, is a thin semilunar fold of the mucous membrane, the concavity of which is turned towards the eye (Fig. 79); this is the rudiment of the *membrana nictitans* (from nicto, to wink), or *haw*, of the horse and mammalia generally, and of the *third eyelid* of birds. In front of the edge of this membrane, on the margin of each eyelid, are two little conical eminences, named the *lachrymal papillæ;* in the apex of each of these is a small aperture, the *lachrymal punctum.* These puncta are the commencement of the lachrymal canals, which carry away the secretion of the lachrymal glands.

The *lachrymal gland* in each orbit, is a small almond-shaped body, Fig. 79, 1, Fig. 80, *g*, situated in a slight depression at the upper and outer part of the orbit, between it and the eyeball; it reaches forwards to the upper eyelid, with which a portion of it is connected. This is a compound racemose gland, and its ducts, from six to twelve in number, open on the inner surface of the upper eyelid, just above the outer canthus. The tears are a clear, saline, alkaline fluid, and contain a minute quantity of albuminoid matter; their total solid constituents amount to only 1 per cent.

The *lachrymal canals*, or *canaliculi*, Fig. 79, commence, as already stated, at the lachrymal puncta; they are two short tubes, placed beneath the skin, one above, and one below the lachrymal lake; the superior canal, which is smaller and longer than the lower one, passes upwards and then inwards, the inferior downwards and then inwards, and both terminate in a large membranous bag, called the lachrymal sac.

The *lachrymal sac*, 2, is lodged in the deep lachrymal *groove*, formed in the inner wall of the orbit; it terminates below, in a narrower tube, the *nasal duct*, which extends to the inferior meatus of the nose. The lower end of the nasal duct is somewhat expanded, and is often partially closed by a membranous fold or valve.

The lachrymal sac and canals consist of fibrous and elastic walls, lined internally by mucous membrane. The epithelium of the mucous membrane, in the canals and upper part of the sac, is laminated, squamous, and destitute of cilia; in the lower part of the sac, and in the nasal duct, it is ciliated. This membrane is continuous above, through the canaliculi, with the conjunctiva, and below, through the nasal duct, with the pituitary membrane lining the nose.

The eyebrows, by their elevation and depression, influence the amount of light reaching the eyes; they also serve slightly to protect these organs from foreign bodies, and from the perspiration running down the forehead.

The eyelids, eyelashes, and lachrymal apparatus, are parts admirably adapted for the preservation and protection of the eyes. By means of the two former, the entry of foreign bodies floating about in the air, is prevented, and the eyes are protected from excessive light. The eyelids, besides, play a most important part in cleansing and moistening the surface of the eyeball. In the act of winking, which may be voluntary, but is usually reflex, and consists merely in the rapid shutting and somewhat slower reopening of the lids, foreign bodies are carried inwards, by a kind of sweeping movement, to the lachrymal lake. The secretions of the conjunctiva and glandular appendages of the eye, when flowing in moderate quantity, partly evaporate, but are chiefly conveyed towards the lachrymal puncta, whence the residuary fluid portion passes, partly by capillary attraction, and partly by the action of the orbicularis muscle, and of the tensor tarsi muscle, hence called the *muscle of the lachrymal sac*, into the lachrymal canals and sac, and thence, through the nasal duct, into the nose. Deep and quick inspirations may likewise aid the descent of the fluid, by an exhausting or sucking action. When the secretion of the lachrymal glands is greater in quantity than can be carried away by the lachrymal ducts, the overflow constitutes the tears.

The secretions of the lachrymal gland and conjunctiva moisten the surface of the eye, facilitate the movements of the eyeball, and, preventing loss by evaporation, preserve the transparency of the so-called cornea. The tears are the most abundant of these secretions; but after the loss of the lachrymal gland, the eye still remains moist. The sebaceous secretion of the Meibomian follicles lubricates the margins of the eyelids, prevents their adhesion, and protects them from the action of the tears. An increased flow of tears is excited by the action of strong light, by irritants operating on the conjunctival, nasal, and lingual branches of the fifth cranial nerve, by vomiting, violent coughing, and by mental emotions causing laughing or crying.

The Eyeball.

The *eyeball* or *globe of the eye*, Fig. 80, is a strong closed membranous sac, rudely compared to a globe, but in reality composed of a large segment of one sphere, having a small segment of a lesser sphere affixed to it prominently in front, *c*. The diameter of these two spheres is about as 11 to 7. The eyeball is furnished with a number of small muscles, which closely surround it, and is abundantly supplied with vessels, lymphatics, and nerves. It is attached behind, to the optic nerve, *n*, and is also maintained in position by its muscles, which pass to it from the orbital walls. In front, the eyeball is free. It measures about one inch in its antero-posterior diameter, and about one line more, from side to side. The *coats* of the eyeball are partly *transparent*, partly *opaque*, the former occupying a portion of the front of the eyeball, the latter the remainder of the globe. The former constitutes the *cornea*; the latter, of which only a part is visible, is the white coat named the *sclerotic*. Within this coat, is spread out a black *pigmentary* layer, named the *choroid*, and within this, the *retina*, the delicate nervous expansion of the optic nerve. The interior of the globe is partially divided into two parts by a perforated septum, named the *iris*, and is occupied by certain transparent media, called *humors*. The rays of light penetrate the transparent coat and media, to reach the back part and sides of the interior of the eyeball; passing through the opening in the iris, and impinging on the retina, they form upon it definite images of external objects. The effects of such impressions are conveyed by the optic nerve to the sensorium, and excite the sensation of light.

A straight line passing directly backwards, through the centre of the cornea, or transparent part of the eyeball, is named its *antero-posterior*, *visual*, or *optic axis.* This does not correspond with the axis of the orbit, which passes obliquely backwards and inwards. The antero-posterior axes of the two eyeballs are *parallel* when the eyes are at rest, and also in certain motions. The *optic tracts*, on each side, arise

Fig. 80.

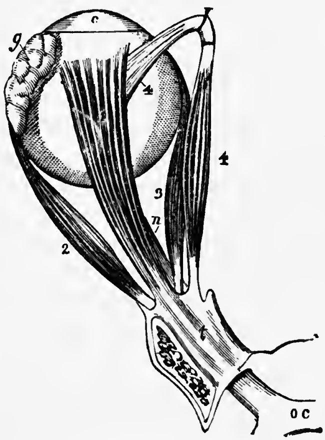


Fig. 80. Left eyeball, seen from above, with a portion of the bone at the bottom of the orbit. the left optic nerve, and the optic commissure, showing some of the ocular muscles. 1, superior rectus muscle. 2, external rectus muscle. 3, internal rectus muscle. 4, 4. superior oblique muscle, passing through the trochlea or pulley, by which the direction of its tendon is changed, before it is inserted into the eyeball. *t*, common tendinous origin of the ocular muscles, surrounding the optic foramen, at the bottom of the orbit. *g*, the lachrymal gland. *c*, the transparent coat of the eyeball or cornea. The rest of the eyeball is covered by the sclerotic. *o c*, the optic commissure. *n*, the left optic nerve passing obliquely forwards, in the axis of the orbit, to reach the eyeball. The antero-posterior axis of the eyeball, when at rest, is not oblique, but is directed forwards, the axes of the two eyeballs being then parallel.

from the optic thalami and corpora quadrigemina, and may be regarded as prolongations of the cerebrum, rather than as nerves; they converge, and join in the middle line, to form the *optic commissure*, *o c*, from which, in front, the optic nerves are given off. These nerves diverge to enter the optic foramina, *t*, of the orbits, where they receive a protecting sheath from the dura mater, processes from which pass between the nervous funiculi. Each nerve, after entering the orbit, pierces the sclerotic and choroid coats of the eyeball, about $\frac{1}{10}$th of an inch to the nasal side of, and a little below, its antero-posterior axis, and then expands into the retina.

The *muscles* which move the eyeball are six in number. Of these, four are called straight, and two oblique. The *straight*, or *recti*, muscles are named, respectively, the *superior*, 1, *inferior*, *external*, 2, and *internal*, 3, *rectus.* They arise from the borders of the optic foramen, where they surround the optic nerve, and pass forward, to be inserted respectively into the upper, lower, outer, and inner sides of the eyeball, on its opaque, or so-called sclerotic coat. The oblique muscles are named, the one *superior*, the other *inferior*. The superior oblique, 4, 4, arises, like the recti muscles, from the border of the optic foramen, and passes forward to the upper and inner side of the orbit; there, it ends in a small tendon, which runs through a fibro-cartilaginous *pulley*, or trochlea, attached to the bone in this situation, and lined by a synovial membrane; hence this muscle has received the name of the trochlear muscle. From the pulley, the tendon of the superior oblique muscle is reflected backwards and outwards, to be inserted into the sclerotic coat, on the upper surface of the eyeball, a little behind its middle. The *inferior* oblique muscle arises from a depression in the inner and fore part of the floor of the orbit, passes outwards and backwards, beneath the eyeball, and is inserted into the sclerotic coat, upon the outer and posterior surface of the globe.

The straight muscles are so attached, that they can turn the eyeball upwards, downwards, inwards, or outwards, according to the muscle brought into play; hence they have been named respectively, the *attollens*, *depressor*, *adductor*, and *abductor* muscles of the eyeball. If two adjoining recti muscles act together, the eyeball is carried in an intermediate or oblique direction. When all four muscles act simultaneously, the eyeball must be strained backwards, and some have supposed that by this action, the antero-posterior diameter of the eyeball may be increased. When in a state of rest, the elasticity of the surrounding structures, keeps the eyeballs in their parallel position, and this parallelism is accurately maintained in many of its movements. But if one muscle becomes weaker than its antagonist muscle, or obtains an undue preponderance over it, the natural position of equilibrium is destroyed, and the distortion named *strabismus* or *squint*, either internal, or external, for example, is produced. The oblique muscles rotate the eye on its antero-posterior axis, the superior oblique rolling its upper half inwards, the inferior oblique rolling its lower half inwards. These two muscles, being inserted *behind the transverse axis* of the eyeball, also turn its anterior surface outwards and downwards, when the superior oblique acts alone, and outwards and upwards, when the inferior oblique acts alone. Their combined action turns the anterior surface of the ball directly outwards.

The upward and downward movements of the eyeballs, are more rapid than those from side to side, or than the oblique movements; the motions, which are very perfectly under the control of the will, are so rapid as to be singly immeasurable, but by repeating them over several times consecutively, in each direction, the difference is multiplied, and becomes easily noticeable. All these movements are more easy of execution, if they are performed from the natural, or, as it were, instinctive position of rest of the eyeballs—that is, with the optic axes directed horizontally forwards, and in parallel lines. The primary or simple motions of the eyeballs, may be referred to rotations around three principal axes—viz., the *antero-posterior* axis, the *transverse* axis, and the *vertical* axis. The movements around the vertical axis are performed by the external and internal recti; those around the transverse axis, by the superior and inferior recti, aided respectively, by the *inferior* and *superior* oblique muscles; the movements around the antero-posterior axis, are exceedingly slight, and are performed by the aid of the oblique muscles. In these simple movements, the eyeball may practically be regarded as a sphere turning round its centre as a nearly fixed point. But besides these movements, the eyeballs are capable of executing oblique motions, as, *e. g.*, upwards and outwards, upwards and inwards, downwards and outwards, and downwards and inwards; in such movements, the eyeball moves around intermediate *secondary axes*, formed by the junctions of two others, and the movements are executed by three muscles—viz., by two of the recti with one of the oblique. Finally, with these secondary movements, and also with the primary ones, are usually combined the very slight rotatory movements of the eyeballs around their antero-posterior axes, so producing *tertiary* movements. In this way, the antero-posterior axis, and therefore, the centre of the cornea, and the centre of the retina, may describe either *straight* or *curved* lines over the field of vision, from one point to another, in every conceivable way—as for example, when we trace the contour of a very complicated figure. Rüte's *ophthalmotrope* is an instrument consisting of a movable ball, to which are fixed elastic cords in a state of slight tension, representing the various muscles of the eyeball; the amount of shortening or elongation of the cords, in any given portion of the ball, is taken to indicate the actions of the respective muscles.

The movements of the eyeball are undoubtedly voluntary, but they present certain peculiarities of very great interest. Thus, the movements of the two eyeballs are always simultaneous and definite; they are always harmonious, but very frequently not symmetrical. In looking upwards or downwards both eyeballs move harmoniously and symmetrically, the same muscles being called into play in each orbit; in looking to the right or to the left, the eyeballs move harmoniously, but unsymmetrically, different muscles acting on the two sides. In oblique movements to one or other side, the motions are unsymmetrical, being produced, for example, by the superior and external recti of one side, and the superior and internal recti of the other; in rotatory movements, the actions, though harmonious and wonderfully exact, are unsymmetrical, being executed by aid of the superior oblique of the one eye, and the inferior oblique of the other; lastly, in convergence of the two eyeballs to look at a near object, the action is both harmonious and symmetrical, the internal recti muscles being called into play in each orbit. Again, it is to be remarked, that the movements of the eyeballs are voluntary, and their muscles decidedly under the influence of the will; yet their motions are limited by a certain kind of *combination*, which prevents us from acting upon them in a wholly independent way on the two sides, as we can, for example, with our arms and hands. Thus, we cannot turn one eyeball up and the other down; nor both eyes outwards; nor can we depart from a certain fixed degree of convergence of the eyes, required for their accommodation to see a given object. The reason of this is, that the movements of the eyes, though voluntary, are guided indirectly by the purposes we strive to attain, which we shall hereafter see are *single* vision with the two eyes, and *exact* vision. The muscles in this case, as in most others, are governed, not directly but indirectly, by our endeavoring to accomplish a certain end; and as we cannot see an object singly by directing one eye upwards and the other downwards, or both eyes outwards, we cannot accomplish those acts. If, however, the position of the image in one eye be slowly displaced sideways, upwards, or downwards, by means of a prism, held and turned slowly before the eye, then the eyeball in question is moved within certain limits to one side, or up or down, so as to maintain the singleness of vision; when the prism is removed the object is, though for a short time only, seen double. All the movements of the eyeball, excepting that of rotation around the antero-posterior axis, which is performed by the oblique muscles, may, by practice, be executed, without the exercise of vision, when the eyelids are closed, but with more or less difficulty or restraint; convergence of the eyes, as in squinting, is the most difficult to imitate. The inability to rotate the eyes by a direct volitional act, is due to the fact that we have not learned how to accomplish it, and not to any special structural limitation. (Helmholz.) This rotation is shown by Helmholz to be of great importance under certain circumstances; for example, in maintaining the meridian plane of the eye in a uniform position, as to verticality, in its various secondary movements, and also in accomplishing certain special adjustments necessary for stereoscopic vision.

The eyeball is supplied with motor, sensory, and sympathetic *nerves*, derived from the third and fifth cranial nerves, and from the lenticular or ophthalmic ganglion. The so-called *ciliary nerves*, from twelve to fifteen in number, perforate the sclerotic, and are distributed to the choroid coat, to the iris, and to a muscular structure known as the ciliary muscle. The *ciliary arteries* derived from the ophthalmic artery, are fine, of considerable length, and pursue a somewhat tortuous course before they enter the eyeball. The *veins* are fewer, but large.

The *coats* of the eyeball are the *cornea* and *sclerotic*, the *choroid* and the *retina*.

The *sclerotic* coat, Fig. 83, *s*, so named from its comparative firmness, forms the outermost tunic of the larger spheroidal portion or posterior $\frac{5}{6}$ths of the eyeball, leaving an opening in front, into which is fitted the transparent structure called the cornea, corresponding with the smaller spheroidal portion, or remaining $\frac{1}{6}$th of the eyeball. The sclerotic is a strong, opaque, fibrous structure, composed essentially of white fibrous tissue, arranged in interlaced bundles mixed with elastic tissue, and in its deeper layers with pigment fibres; its vascularity is not great. It is perforated behind by the optic nerve, *h*, and presents, at the place of perforation, or *lamina cribrosa*, a number of minute orifices for the passage of the nervous funiculi; in the centre of this lamina is a larger opening called the *optic pore*, for the transmission of the small artery which supplies the retina, the *central artery of the retina*.

The *cornea*, *c*, or the transparent convex structure, which occupies the opening in the anterior part of the sclerotic, like a sort of watch-glass set in its frame, is not quite circular, being somewhat broader transversely than from above downwards. Its convexity varies in different individuals; it is more convex in early life, and in short-sighted persons, and becomes flattened in old age. The radius of its curve is said to range from rather more than $\frac{1}{4}$th to nearly $\frac{1}{3}$d of an inch. Like the sclerotic, the cornea is composed of fibres, but these are arranged more regularly, and are separable into closely-connected layers; its anterior and posterior surfaces are formed by specially-condensed, structureless, and highly elastic laminæ. The inner surface of the cornea forms the anterior boundary of a space within the eyeball, called the *anterior chamber*, *a*, and is lined by a single layer of flat, polygonal, epithelial cells. Its anterior surface is covered by a very fine extension of the conjunctiva, which reaches it from the fore part of the sclerotic. Where the sclerotic joins the cornea, the character and arrangement of the constituent fibres are altered, so that they form a transparent, not an opaque coat. Both these structures are supplied with nerves; but the cornea is non-vascular, and must receive its nutrient supply, indirectly, from the sclerotic and conjunctival vessels. The sclerotic is about $\frac{1}{20}$th of an inch, and the cornea about $\frac{1}{25}$th of an inch in thickness.

The *choroid* coat, *e*, is a comparatively thin, tender, vascular, black or brown, pigmentary membrane, which is perforated behind by the optic nerve, and reaches forwards as far as a circular fibro-elastic band, corresponding with the line of junction of the cornea with the sclerotic, named the *ciliary ligament;* with this, the anterior edge of the choroid coat is firmly united. The outer surface of the choroid is loosely connected with the sclerotic, by bloodvessels, nerves, and a fine cellular web, the *lamina fusca;* within this, are curious whorled veins, *venæ vorticosæ*, and numerous branching arteries, mixed with star-shaped pigment cells; within these, is a network of exceedingly fine and close capillaries; and lastly, the *pigmentary* layer, made up of regularly-hexagonal nucleated cells, filled with pigment granules, Fig. 43, *d*. The choroid averages about $\frac{1}{264}$th of an inch in thickness.

The *ciliary ligament*, just mentioned, placed opposite the junction of the sclerotic with the cornea, serves to connect those coats with the choroid, and also supports numerous black or brown radiated folds or rays, called the *ciliary processes*, Fig. 83, *b*, which are prolongations of the fore-part of the choroid. These processes, from 60 to 80 in number, are situated in a radiated manner around the margin of the crystalline lens, to be presently described; some of them, the larger ones, are about $\frac{1}{10}$th of an inch in length, and $\frac{1}{40}$th of an inch thick, between which smaller ones are found. In these processes, the capillary network is larger than in the choroid.

On the surface of the fore-part of the choroid, is a yellowish-pink band, about $\frac{1}{8}$th of an inch broad, the *ciliary muscle;* this consists of involuntary muscular fibres, some having a longitudinal, others a circular direction; the former arise from the line of junction of the cornea and sclerotic, opposite the ciliary ligament, and posteriorly, are inserted into the iris, the sclerotic ciliary processes, and the anterior part of the choroid. This muscle has also been named the *tensor of the choroid.*

Stretched across the interior of the eyeball, and attached by its circumference, to the choroid, ciliary ligament, and cornea, is the thin membranous curtain, called the *iris*, Fig. 83, *i*, Fig. 81, *i i*, perforated

Fig. 81.

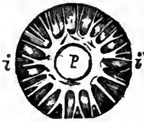


Fig. 81. The iris or perforated colored diaphragm, removed from the eyeball. *i i*, its outer attached border. *p*, the pupillary opening in its middle.

a little to the inner side of its centre by a circular opening, the *pupil*, *p*. The contraction and dilatation of this aperture, regulate the amount of light which passes into the eye. In health, the size of the pupil varies from $\frac{1}{20}$th to $\frac{1}{3}$d of an inch. After death, its average diameter is nearly $\frac{1}{4}$th of an inch. The anterior surface of the iris, which is flat, contains pigment cells; it is brilliantly reflective, and gives the eye its special color. The iris and pupil appear to be larger and nearer to the cornea than they really are; placing the eye under water, removes this deceptive appearance. The iris is composed of unstriped muscular fibres, a fibrous stroma, bloodvessels, nerves, and a quantity of pigment cells. The muscular fibres consist of circular and radiating fibres; the *circular* fibres, placed at the back of the iris, opposite the ring named the *annulus minor*, form a narrow band, the *sphincter pupillæ;* the *radiating* fibres pass from the circumference towards the pupil, near the margin of which they blend with the circular fibres, which here lose their parallel arrangement. The fibrous stroma is made up of delicate bundles of fibrous tissue, the greater number of which radiate towards the pupil; others are arranged in a circular manner. The bloodvessels form loops. The pigment cells in the substance of the iris are ramified, and are of a yellow or brown color, according to the color of the eye; on the posterior surface, the pigment cells are of a dark-brown or black hue, and consist of several layers, forming what is called the *uvea*. These cells are, as a rule, darker in children than in adults; in the former, the delicate pale blue tint of the white of the eye, is due to the sclerotic coat being very thin, so that the pigment within, can be partly seen through it; the pigment cells are also darker in dark persons, and in the swarthy races of mankind.

Within the choroid, is the *retina*, or the sensitive coat of the eyeball, Fig. 83, *r*. This structure is a delicate nervous membrane formed by the expansion of the optic nerve. It is so supported as to present a concave surface to the light; it does not extend so far forward as the choroid, but ends, at a short distance from the ciliary ligament, in a jagged edge, called the *ora serrata*, from which an exceedingly fine membrane, not nervous, extends forwards to the ciliary processes. By its outer surface, the retina is slightly, though organically, connected with the choroid; its inner surface is bounded by a very delicate membrane, called the *membrana limitans*, which separates it from the so-called vitreous body. As seen during life, by the aid of a magnifying glass, the retina presents a reddish color, due to the bloodvessels contained in it. Branches of the central artery of the retina are seen ramifying over it; and these, as well as the capillary network, are situated upon, or near, its inner surface. When examined immediately after death, the retina is found to be of a pinkish color, soft, and transparent; but it quickly becomes white or semi-opaque. In the centre of the back of the eyeball, *i. e.*, exactly in the antero-posterior axis of the globe, and, as we shall explain, in the line of most perfect vision, the retina presents, soon after birth, an elliptical yellowish spot about $\frac{1}{12}$th of an inch wide, called the *macula lutea;* in the middle of this *yellow spot*, the margins of which are slightly elevated, is a darker circular depression, named the *fovea centralis* (fovea, a pit). The retina being exceedingly thin in this situation, the pigment of the choroid is seen through it, and this gives rise to the deeper color of the fovea centralis; the yellowish margin of the macula lutea, is owing to the presence of some special but delicate pigmentary matter. A little below the yellow spot, and about $\frac{1}{10}$th of an inch internal to it, is the *colliculus*, or point of entrance of the optic nerve; the central artery of the retina also passes into the eyeball at the same place. The thickness of the retina gradually diminishes from behind forwards; its thickness varies from $\frac{1}{120}$th to $\frac{1}{240}$th of an inch.

Examined microscopically, the retina is found to consist essentially of three layers, which are held together by a very delicate connective tissue; it also contains bloodvessels. The *external* layer, formerly called *Jacob's membrane*, and now the *bacillary layer*, is very thin, and consists of a stratum of evenly-disposed, transparent, colorless *rods*, called *bacillæ*, intermixed with other larger bodies, named *cones*. These rods are solid and highly-refractive bodies, packed closely side by side, and, except those near the anterior part of the retina, which, at least in the frog, are disposed obliquely, are arranged more or less nearly perpendicularly to the centre of the eyeball; under the action of water, these rods swell, undergo distortion, and show a division into an outer and inner segment; the outer segment is the more highly refractive; the inner one, which becomes curved on the application of water, is connected with a fine fibre, which passes vertically inwards, into the next or middle layer of the retina. The cones, or bulbous particles, disposed at regular intervals between the rods, present a similar structure, and the same connection with the middle retinal layer. The diameter of the rods is, on an average, $\frac{1}{13750}$th, that of the cones about $\frac{1}{3666}$th of an inch. The *middle* layer of the retina, also named the *granular* layer, consists of two strata of granular or nucleiform bodies, which are connected, on the one hand, with the fine fibres proceeding from the rods and cones, and on the other, by fine processes, with the nervous elements belonging to the third or so-called nervous layer of the retina. Amongst these nuclear fibres, are some, forming the *radiating fibres* of H. Müller, which pass through the whole thickness of the retina, from between the rods and cones of the outer layer, to the membrana limitans, on its extreme inner surface, on which they end by slightly-expanded extremities. These radial fibres support the whole structure of the retina, passing between the nervous elements of the inner layer, and also between the capillary network. They may merely be modifications of connective tissue; but others of the *nuclear* fibres are distinctly connected with the rods and cones on the one hand, and with the proper nervous elements of the deepest layer on the other, and are themselves probably true nervous structures. The *internal*, or *nervous*, *layer* consists partly of the expanded fibres of the optic nerve, which pierce the bacillary and granular layers at the optic colliculus, and then spread out, to form the *retinal network*, in which the nerve-fibres, losing their double outline, and retaining only their central or axial fibres, are arranged in fine meshes among the radiating fibres of Müller. The nerve-fibres are here very fine, measuring only from $\frac{1}{6000}$th to $\frac{1}{50000}$th of an inch in diameter. Between this network and the granular layer, is found a stratum of large gray ganglionic vesicles or nerve cells, with ramified offsets, similar to those found in the gray substance of the brain; hence this layer is sometimes named the *vesicular* layer. The offsets or processes of these cells, are said to be connected, on the one hand, with the nuclear fibres proceeding to the rods and cones, and on the other, with the axial fibres of the retinal expansion of the optic nerve; whilst some of the fine nerve-fibres are also said to be traceable directly into certain of the nuclear fibres, and, through them, to be connected with the rods and cones. The capillary vessels chiefly lie in the neighborhood of the layer of ganglionic vesicles.

From the intimate connection of all these complex elements of the retina, most physiologists are of opinion, that whilst some of the radiating fibres are possibly only supporting structures, others, as well as the rods and cones, are either actual nervous elements, or important appendages of the extremities of the nerves.

At the fovea centralis of the yellow spot, only certain of the retinal elements are present, viz., the cones of the columnar layer, which are here smaller and set closely together, a stratum of gray ganglionic nerve-cells, and the membrana limitans. At the elevated margin of the yellow spot, the other ordinary retinal structures, which are absent in the fovea centralis, begin to appear. At the optic colliculus, the only elements present are the nerve-fibres, radiating from that point.

The transparent humors of the eyeball are, the *vitreous humor*, the *crystalline lens*, and the *aqueous humor*.

The *vitreous humor*, Fig. 83, *v*, so named from its glass-like transparency (vitrum, glass), occupies about the posterior $\frac{4}{5}$ths of the entire globe, and measures from before backwards about half an inch. It is a colorless, transparent, jelly-like mass, inclosed in a clear membrane, called the *hyaloid membrane*, processes of which also traverse it. The vitreous humor consists of a specially modified connective tissue, called *jelly-like* or *mucous*, arranged in segments, like an orange. It is composed almost entirely of water, in which are some salts, and a little animal matter. Behind and around, the vitreous humor is convex, and supports the retina; in front, it is cup-shaped, for the reception of the crystalline lens.

The *crystalline lens*, Fig. 83, *l*, is a double convex, colorless, transparent, firm body, placed in front of the vitreous humor; it receives its name from its crystal-like appearance and its lenticular shape. It is inclosed in a transparent, structureless, highly elastic, and permeable membrane, called the *capsule of the lens;* between the capsule and the body of the lens is a single layer of transparent nucleated cells; these cells, after death, imbibe moisture, and then, breaking down, form a liquid layer, the *liquor Morgagni.* The lens is chiefly supported in its place by a transparent and highly elastic membranous structure, called the *suspensory ligament;* attached to the anterior surface of the capsule, close to the margin of the lens, this ligament is connected behind with the ciliary processes, and with the hyaloid membrane, which incloses the vitreous body; it may be traced as far back as the ora serrata of the retina. It presents on its anterior surface a number of folds, which fit in between the rays of the ciliary processes. Around the margin of the lens, between the hyaloid membrane and the suspensory ligament, is a circular passage, called the *canal of Petit.*

The posterior surface of the lens is embedded in the depression on the forepart of the vitreous humor; its anterior surface, which is free, is placed in contact with the iris, behind the pupil. The superficial portion of the lens is soft; but towards the centre, it gradually becomes firmer and denser; the central and firmest part is named the *nucleus.* The posterior surface, Fig. 82, *d*, is more convex than the anterior; the curvature of both surfaces, the anterior of which is said

Fig. 82.

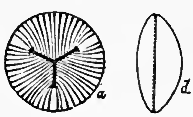


Fig. 82. Two diagrammatic views of the crystalline lens; *a.* anterior surface, showing the radiated arrangement of its component bundles of fibres, which are here seen to meet on three planes; *d*, side view, or edge of the lens. The anterior flatter surface is here turned to the left hand, and the posterior more convex surface, to the right.

to be ellipsoidal and the posterior paraboloidal, increases towards the circumference; its edges are rounded off. The lens measures about $\frac{1}{4}$th of an inch in its antero-posterior diameter, and about $\frac{1}{3}$d of an inch transversely. The radius of the curve of its posterior surface is about $\frac{1}{4}$th of an inch; that of the anterior surface varies, from somewhat more than $\frac{1}{4}$th to about $\frac{1}{5}$th of an inch. The substance of the lens is composed of concentric layers, which are made up of microscopic parallel fibres, by some said to be tubular (Kölliker); they have uneven or indented margins, which fit together most accurately. Towards the centre of the lens, these fibres meet in certain planes, *a*, which radiate from the central axis of the lens; in the nucleus, there are three principal planes; in the superficial portion, there are as many as twelve. The lens consists of about 60 per cent. of water; the solid matter is chiefly albuminoid.

Before birth, the lens is nearly spherical, very soft, and not quite transparent, its fibres being then imperfectly developed. At this period, a small artery traverses the vitreous humor to the back of the lens; here its branches form a plexiform network on the back of the capsule. In front of the lens, this network of vessels is met by a vascular extension from the pupillary margin of the iris, constituting the *pupillary* membrane, which then closes the pupil. By means of these vascular membranes, the humors of the eyeball are nourished during their growth. Shortly before birth, the pupillary membrane gradually undergoes absorption, so that, at birth, almost all traces of it have disappeared. In some rare instances, however, this structure is not absorbed, but remains as a permanent part of the eyeball; in such cases, sight is necessarily interrupted.

Between the front of the crystalline lens and the posterior surface of the cornea, is a small space, measuring, from before backwards, about $\frac{1}{10}$th of an inch, and occupied by the *aqueous humor*. This interval is divided, before birth, by the pupillary membrane, into two parts, called the *anterior* and *posterior* chambers. In the fully-formed eyeball, the iris is often described as also imperfectly dividing the space occupied by the aqueous humor, into an anterior and posterior chamber; but it has been shown that the iris rests immediately upon the anterior surface of the capsule of the lens, so that there is no posterior chamber, or interval between them. The aqueous humor consists of about five drops of a limpid fluid, resembling pure water; it contains a little salt, and a trace of animal matter. It is probably secreted by the posterior surface of the cornea, and by the vessels of the iris and of the points of the ciliary processes.

The following table shows, in decimal parts of an inch, various measurements of the eyeball and its parts (Krause):

a. Diameters of the eyeball, through its centre:

	Inch.
Antero-posterior,	.944
Vertical,	.944
Horizontal,	1.003

b. Thickness of the various parts in the direction of the antero-posterior axis:

Cornea,	.0393
Aqueous humor,	.0984
Crystalline lens,	.2755
Vitreous body,	.4921
Retina and choroid,	.0078
Sclerotic,	.0511

c. Radii of the curves of the surfaces of the refracting media:

Cornea,	.275 to .314
Anterior surface of lens,	.275 to .393
Posterior " "	.236

Light.

Those bodies, such as the sun and fixed stars, from which light directly emanates, are called self-luminous bodies. The sun is the chief source of light, but there are also terrestrial sources of light, such as combustion and other chemical combinations, friction, and electricity. Non-luminous bodies are only rendered visible by the light which falls upon them from luminous bodies.

According to the Newtonian theory of emanation, light is of a corpuscular nature, a luminous body constantly emitting material particles in all directions. The undulatory theory of light, first suggested by Huyghens, and now generally adopted, supposes, that space is filled with an ether, which, when thrown into exceedingly rapid *undulations* gives rise in the eye to the *sensation of light*, as the vibrations of material particles, communicated to the ear, produce the sensation of sound. In accordance with the doctrine of the correlation of forces, the undulations of light are supposed to result from one of the modes of action of the general force of nature, and therefore to be able to originate in mechanical, chemical, thermal, or electrical modes of action.

The undulations of the luminiferous ether being supposed to be propagated from a luminous point in *all* directions, the term *ray*, a conventional but convenient expression, is applied to any imaginary line drawn from such a point across the waves, that is, perpendicular to their expanding and advancing fronts. The undulations are therefore propagated in the direction of such lines or rays; but the motions of displacement of the ether which produce those waves, are *transverse* to the direction of the rays.

The so-called *rays* of light *move* in straight lines; their rate of motion, in space, formerly estimated at 192,500 miles, is now said to be about 186,300 miles per second; their velocity is retarded in dense media. Light radiates equally in all directions, and, by spreading, its luminous power diminishes as the square of the distance through which it passes. When it falls upon any surface, it may be either *reflected* or *absorbed.* The angle of reflection is equal to the angle of incidence. The reflection is said to be regular, when the reflected light from an opaque body with a polished surface, produces images of objects placed in front of it; by multiplying such surfaces, the reflected images are broken; and, if the surface be rough, no image is formed, the light is scattered, and its reflection is irregular. It is by the reflection of the light which impinges upon non-luminous, opaque, or transparent objects, from luminous bodies, that the former are rendered visible. Such objects, when they reflect light, completely or almost completely, present a white or whitish appearance: but, if there is complete or almost complete absorption of light, they assume a black or blackish appearance. The interception of a portion of the rays of light by opaque bodies, is the cause of shadows. When light falls on a translucent body, it is partly reflected, partly transmitted, and partly absorbed; when it falls directly on a transparent body, such as air, water, or glass, it is almost all transmitted; but absorption of some rays takes place.

Light is either *colorless* or *colored.* White or colorless light, when reduced in intensity, forms a bluish-gray tint, gradually passing into blackness, which is usually regarded as dependent on the relative or nearly total absence of light. Black, however, is by some considered to be a positive sensation.

Luminous bodies generally give off rays of light composed of several colors. Thus, solar light, though apparently white, may be *decomposed*, by aid of a prism, into several colored lights. When a small beam of solar light, admitted through a circular opening in a shutter or other septum, falls on one side of a prism, or three-sided piece of glass, its component rays are so *dispersed* or *spread out*, that if an opaque screen be placed behind the prism, an *elongated* luminous image is produced. This, which is named the *prismatic solar spectrum*, is not white, but colored, like the rainbow, presenting bands of violet, indigo, blue, green, yellow, orange, and red. These colors appear to consist of various combinations of three different colored lights, viz., red, yellow, and blue, or, according to Sir J. Herschel, red, *green*, and blue, which therefore are named the three primary colors. Others maintain that the seven colors of the spectrum, as they cannot be further analyzed, are the primary, simple, optical, or homogeneous colors.

The different colored lights are said to differ as regards the number of undulations of the hypothetical luminiferous ether which excites them. The extreme red rays of the spectrum, for example, are calculated to undergo undulations numbering 399 billions in a second; whilst the undulations of the other colors of the spectrum are said to increase *progressively* in number, the extreme violet rays performing 831 billions of undulations in the second. The more numerous the undulations, the shorter are their component waves. Color *in the eye* is due to *specific sensations* in the retina, excited, according to the theory just mentioned, by undulations of different velocity and length; yet why such relations of color to differences in the number and measurement of the undulations, should exist, is not obvious.

Besides the visible rays, or rays capable of exciting luminous sensations in us, solar light contains certain *invisible rays*, or rays incapable of exciting such sensations, excepting under certain conditions. These rays are also dispersed in the prismatic spectrum, and project, some beyond the violet end, and some beyond the red end, where they form the so-called ultra-violet and ultra-red rays. It may be conceived that these rays undulate, in the former case too rapidly, and in the latter too slowly, to act upon the retina.

There are certain bodies, such as fluor-spar, and many decoctions of organic substances, such as the bark of the horse-chestnut, and the seeds of stramonium, also an alcoholic solution of chlorophyll, and, more especially, a solution of sulphate of quinine in water, which give rise to the formation of internal color from the passage through them of solar light. The color, in the case of a solution of quinine, has a beautiful pale blue tint; in other solutions, it may be yellow, yellowish-orange, or red. This appearance of color is known as *fluorescence*, and is produced by a change in the condition of the transmitted light, caused by the substance experimented on, and named *internal dispersion* (Stokes). The rays concerned in this phenomenon, exist also in the colored prismatic spectrum, but they pass considerably beyond the extreme violet end. They constitute, under ordinary circumstances, invisible ultra-violet rays. When, however, a solution of quinine is held beyond the violet end of the spectrum, it becomes bluish or fluorescent, thus rendering these peculiar rays visible; so also when a sheet of paper, moistened with a solution of quinine, is held in the same position, it becomes beatifully luminous. Clear water and ordinary white paper, held in the same place, are not illuminated. The electric light contains many of these invisible rays.

Again, beyond the red rays of the solar and electric spectra, there are invisible rays, some of which are found, in decreasing numbers, in the rest of the spectrum. These rays give rise to the remarkable phenomena occurring at this end of the spectrum, known under the name of *calorescence* (Tyndall). By passing the rays of the electric light, brought by means of a mirror to a focus, through a solution of iodine in bisulphide of carbon, the luminous rays are completely stopped; but certain invisible rays, which, in the electric and solar spectrum, are found chiefly near, and beyond, the red end of the spectrum, continue to pass, and produce at the focus, a heat sufficiently intense to set fire to combustible substances. The phenomena of calorescence occurring at, and beyond, the red end of the spectrum, have been compared with those of fluorescence at, and beyond, the violet end. The combustion of oxidizable substances by these dark rays, affords an example of the conversion of obscure radiant heat into light.

These heating rays have been called *calorific* rays; whilst certain of the rays at the violet end of the spectrum, are called *chemical* or *actinic* rays, on account of their power of exciting chemical or photographic action. The colored rays are named *colorific*.

Light is said to undergo a decomposition by *absorption*, as well as by dispersion through a prism. Thus, the great variety of color presented by opaque bodies when viewed by solar light, is due to absorption by them, in most variable proportions, of the rays of one, or more, of the three, or seven, primary colors, and the reflection of the remaining rays. In this manner, a blue body is said to absorb, more or less completely, the red and yellow, and to reflect the blue rays; a red body absorbs the blue and yellow, and reflects the red; whilst a yellow body absorbs the red and blue, and reflects the yellow rays. Secondary colors, or compounds of two primary colors, are produced, when a body absorbs one primary color and reflects the other two; thus the absorption of the blue rays, and the reflection of the red and yellow, give an orange color; in the same manner, the absorption of red alone gives a green color, and the absorption of yellow, a purple color. Tertiary colors, as olives, grays, drabs, are produced when the three primary colors all undergo more or less absorption and reflection. That color which is necessary, in regard to another, to complete a white light, is called its *complementary* color; thus orange is the complementary of blue, and blue of orange; again, yellow and purple, and red and green, are, in the same manner, complementary colors. Such complementary colors may be primary or secondary. If decomposition by absorption takes place of all the white light reflected from the surface on which it falls, the color of the object is intense; but if part of the white light be not decomposed, the reflected color is diluted by it, and is much less intense. Translucent bodies may decompose white light, in this manner, both reflecting and transmitting various colors. Those transparent bodies or media, which, besides transmitting light, cause its decomposition by absorption, are both colored and transparent. It has already been mentioned, that absorption of some of the rays always takes place when light passes through a body, however great its transparency; it is thus that the phenomena of aerial perspective are produced. The rays given off by artificial lights present many varieties in color. Some are monochromatic, giving out but one color. Their calorific or heating power, and their chemical action, are all exceedingly different. All such artificial rays are less powerful than the solar rays.

Rays of light, as already stated, travel in straight lines; and so long as they pass through a medium of uniform density, and also when they pass from a rarer into a denser, or from a denser into a rarer medium, as from air into glass (Diagram H, P), or from glass into air, *p*, in a direction *perpendicular* to the surfaces of the media, they continue to move on in straight lines, P *p*. But when rays pass obliquely, O, from one medium into another of different density, they are *bent* out of their straight course, undergoing what is called *refraction*. When the rays

Diagram H.

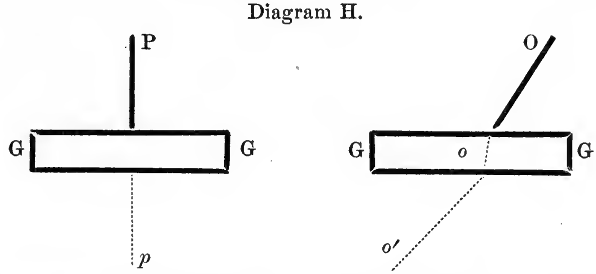


Diagram H. Showing simple refraction of light. G, G, piece of glass. P. *p*, perpendicular ray of light, passing from air into glass, and from glass into air, without change of direction. O, oblique ray, bent, on passing from air into glass, *o*, and again bent, *o′*, on passing from glass into air.

pass from a rarer into a denser medium, O, *o*, they are bent *towards* a line perpendicular to the surface of the media, at the point of incidence; but when rays pass from a denser into a rarer medium, *o*, *o′*, they are bent *from* that perpendicular. The incident and the refracted rays always lie in the same plane. The refractive powers of different media present considerable differences; thus the refractive index, or relative refractive value of air, vacuum being taken as 1, is 1.003, of water 1.33, of flint glass 1.642, of the diamond 2.755. The amount of refraction increases with the obliquity of the incident rays; this increase follows "the law of the sines." The refractive power of a medium increases generally with its density, and with the retardation of the light passing through it; the refractive power of combustible bodies is, however, greater than their density would indicate. The spreading or *dispersion* of the white solar beam by a prism, into the colored spectrum, already described (p. 431), is explained by assuming that its different colored rays, have different degrees of *refrangibility*. The violet, or most rapidly undulating rays, are most bent out of their straight course, whilst the red, or more slowly undulating rays, are the least easily refracted or turned aside.

When parallel rays fall directly upon a *double convex* glass *lens*, such as a common pocket-lens, *i. e.*, upon a refracting medium having two spherically convex surfaces, the ray coinciding with its axis passes through, unchanged in direction, without undergoing any refraction; all the other rays, however, are twice refracted, first, on entering, *towards* a perpendicular to their point of entrance into the lens, and then, on issuing, *from* a perpendicular to their point of exit from the lens. These refracted rays, through whatever part of the lens they pass, meet the central rays at a certain point, called the *principal focus* of the lens; the distance of this from the lens, is called its proper *focal distance*, and is determined by the degree of convexity and the refractive power of the lens. As a lens acts either way, it has two principal foci, one opposite the centre of each surface. When the rays of light proceed from a radiant point, situated in one principal focus of a lens, and pass through the lens, the emergent rays are parallel, just as parallel rays converge to the principal focus. When, however, the radiant point is further from the lens than its principal focus, but not so remote that the rays issuing from it enter the lens in parallel lines, then the rays *converge* to a point or focus, which is nearer the lens the greater the distance of the radiant point from its principal focus.

When an object (Diagram I) *a*, *b*, *c*, is placed in front of a lens, *l*, so that the rays of light emitted from its several points, diverge as they fall upon the refracting surface, those which proceed from the central point of the object, *b*, form a *conical pencil* of rays, called a

Diagram I.

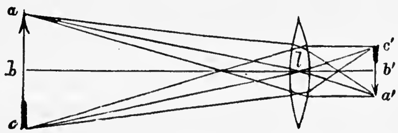


Diagram I. Diagram, illustrating the formation of an inverted image of an object in the focus of a double convex glass lens. *l*, the lens, seen edgeways. *a*, *b*, *c*, an arrow, representing the object. *a′*, *b′*, *c′*, the inverted image of the same. *a*, pencil of rays, from the point of the arrow, refracted on entering, and emerging from, the lens, to meet in the point *a′*. *c*, another pencil of rays, from the opposite end of the arrow, acted on in a similar manner, and converging at the point *c′*. In order to avoid confusion in the diagram, only the central ray of the pencil from the point *b* is here shown; it alone undergoes no refraction.

direct pencil; all the divergent rays of this pencil, after having undergone refraction, converge on the other side of the lens, meeting the central ray, which has passed through without undergoing any change in direction, at, or near, a *common focus*, *b′*. The rays from all the other points of the object form more or less *oblique* pencils. Those oblique pencils which proceed from the extremities or circumference of the object, *a* and *c*, undergo similar, though not such regular refraction as the divergent rays of the direct pencil, and after passing obliquely through the lens, converge to their respective *common foci*, *a′*, *c′*, on the *opposite* sides of the common focus of the direct pencil, *b*. In the same manner, all the rays proceeding from points between the centre and the extremities or circumference of the object, after being refracted, converge to their respective intermediate *common foci*, so that an *inverted* image, *a′*, *b′*, *c′*, of the object, *a*, *b*, *c*, is thus formed. The formation of such an inverted image, may be readily shown by holding a lighted candle on one side of a lens, and a screen of white paper on the other; it is of special interest to the physiologist, for this optical phenomenon actually takes place in the eye.

In the production of images by artificial lenses, there are several sources of imperfection. It has already been mentioned that the different colored rays into which solar light may be decomposed, have different degrees of refrangibility; it is in consequence of this unequal refraction, that the images of bodies illuminated by solar or other compound light, formed by an ordinary lens, are surrounded by a fringe of prismatic colors. This defect is called the *error of dispersion* or *chromatic aberration.*

The degree of refraction of the rays which fall on the curved surface of a double convex lens, becomes relatively greater, the greater their distance from the axis of the lens, because they fall upon, and issue from, its surfaces, with greater and greater obliquity. Hence, the peripheral rays are brought to a focus sooner than the central rays, so that every part of the image becomes more or less indistinct and confused. This is called *spherical aberration.* The effect on a small pencil of light, is the production of the so-named *circles of dissipation.*

By cutting off the peripheral rays, by means of perforated stops or *diaphragms*, both chromatic and spherical aberration may be diminished. They may be almost completely corrected, by building up lenses of two pieces of glass, having different curves, and also different dispersive powers, so that the dispersive and undue marginal refractive effects of one portion of the lens, are counteracted by the influence of the other. Such lenses are called *achromatic.*

If an object be situated at such a distance from the lens, that the rays issuing from it are parallel, the best image is formed in the principal focus of the lens. The nearer the object approaches the lens, the more the focus recedes, until at last, the object having reached the principal focus of the lens in front, the rays emerging from the lens become parallel, and accordingly, no image is formed. Hence, in order to obtain a distinct image of any object, the distance between the lens and the screen for the reception of the image, must be varied, that is, increased or diminished, according to the nearness or distance of the object. In optical instruments, provision is made for the proper adjustment of the *focal distance*, by having the lenses, or the screen, made movable. The defect arising from imperfect adjustment of the focus, is known as *distantial aberration.*

The size of the image varies, of course, according to the distance of the object, being smaller in proportion to the greater distance of the object. The degree of convexity of the lens also affects the size of the image; for the greater the convexity of the lens, the shorter is the focal distance, and the smaller the image produced.

When the rays from a straight line, or from a plane surface, placed parallel with the surface of a double convex lens, pass through it, the image is always curved, or concave, towards the lens; and if the screen for its reception be a plane surface, this image is defective, either at the extremities or margins, or else in the centre. This, the error from *curvature*, may be obviated by making the screen concave.

The error called that of *distortion*, is due to the varying distances of the parts of the same object; it therefore chiefly affects the extreme marginal rays proceeding from very long straight objects. It is on this account that the images of the parts of such objects, which lie near to the margins of the lens, are proportionally somewhat smaller than those of the parts lying opposite the centre of the lens.

The errors of curvature and distortion may be diminished by limiting the operation of the lens to its central part, by cutting off the marginal rays with a perforated diaphragm.

Another imperfection, called the error of *confusion*, is due to the increasing irregularity of the refraction undergone by those rays which fall with greater and greater obliquity on the lens. If the marginal rays are intercepted, this error may be diminished; and if the position of the lens be so changed that the rays fall on it directly, instead of obliquely, it is entirely obviated.

A *camera obscura* is a dark box or chamber, painted black in its interior, and having, in its front, an aperture fitted with a double convex lens, made to slide in and out, and, at the back, a screen of some semi-opaque substance, such as ground glass, or tissue paper. When an object is placed in front of the lens at a suitable distance, an *inverted* image of it is projected on to the screen. The distinctness of this image may be diminished or increased, by changing the distance of the lens from the screen; and the introduction of a perforated diaphragm of blackened cardboard, or metal, between the lens and the screen, by cutting off the aberrant marginal rays, will also improve the distinctness of the image, and, at the same time, regulate the quantity of light admitted into the camera. Such a chamber, filled with water instead of air, having a concavo-convex lens fitted into the aperture in its front, and provided, in its interior, with a double convex lens, placed behind a perforated diaphragm, would closely resemble, in its optical arrangements, the globe of the eye, and would form, on the screen behind, inverted images of objects situated in its front.

Sight.

The eyeball, Fig. 83, is a natural camera obscura; it is a dark chamber, colored black, or brownish, within, by the choroid pigment; in front, it presents a convex, transparent, portion, the cornea, *c*, for the admission of light into its interior, as well as for its partial refraction; certain other fluid and solid refractive media, viz., the aqueous humor, *a*, crystalline lens, *l*, and vitreous humor, *v*, are superadded; of these, the crystalline lens is the most important, and represents the internal lens of the water camera obscura; the perforated diaphragm is represented by the iris, *i*, and pupil; lastly, the retina, *r*, occupies the position of the recipient surface or screen. To complete the comparison, when an object is placed in front of the eyeball, at a suitable distance, an *inverted* image of it is projected on to the retina (see the arrow and its image). This image cannot be seen in the *living* eye; but it may be demonstrated in the human eye, and in the eyes of the larger quadrupeds, taken out after death, on removal of a part of the

Fig. 83.

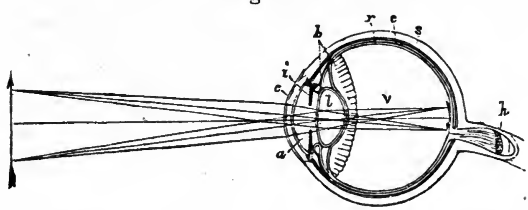


Fig. 83. Diagrammatic section of the eyeball, showing the position of its parts, and the mode of formation of the inverted image of an object on the retina, at the back part of the eyeball. *c*, the cornea. *s*, sclerotic. *e*. the choroid. *b*, the ciliary processes. *r*, the retina. *a*, the aqueous humor. *l*, the crystalline lens. *v*, the vitreous humor. *i*, the iris.—The position of the ciliary ligament, from which the ciliary muscle takes its origin, is at the junction of the cornea, sclerotic, and iris. *h*. the optic nerve. The arrow, with the lines representing pencils of light, and the inverted arrow on the inside of the back of the eyeball, may be compared with the same parts in Diagram I, p. 434.

sclerotic and choroid coats from the back of the eyeball, and even without such dissection, in white rabbits, and other small albino quadrupeds, in which the coats of the eyeball are transparent.

But the eyeball differs, as we shall see, from an artificial camera obscura, in many ways. Its form is globular, not cubical, so that its screen presents a concave surface; its chief refracting medium, the crystalline lens, is capable of special adjustment for objects at different distances; the eye is also corrected for the aberrations of ordinary lenses; its diaphragm has a self-regulated aperture of variable size; and lastly, the recipient screen is a sensitive surface, which becomes excited by the image thrown upon it, in such a definite manner, that distinct and corresponding visual impressions are thereby produced in the sensorium, conveying to the mind, impressions of *light* and *shade*, *form* and *color*.

The eye acts upon light like a compound lens; it consists, indeed, of a compound system of refracting media. Thus the cornea forms a *meniscus*, the aqueous humor, a *convexo-concave*, the crystalline lens, a *double convex*, and the vitreous body, a *concavo-convex* lens. The refractive power, or index, of air being taken as 1.003, and that of water, as 1.33, the refractive index of the cornea is 1.33, of the aqueous humor, 1.34, of the capsule and outer layers of the lens, 1.35, of the succeeding layers of the lens, 1.38, of the nucleus or centre of the lens, 1.41, and of the vitreous humor, 1.35. The mean refractive power of the lens is, by some, estimated as high as 1.45. Rays of light passing from one medium to the other, within the eye, are not refracted, according to the above-mentioned coefficients, which refer to the refractive powers of the several parts, in regard to rays passing from a vacuum. The cornea first refracts the rays, and the aqueous humor may be taken as a part of one system with it; the lens acts as a second system, and the vitreous humor as a third. The rays, on entering the cornea from the air, are powerfully refracted *towards* the perpendicular; in passing from the aqueous humor into the lens, they are again refracted *towards* the perpendicular, but only in proportion to the *relative index* of refraction of the several media, found by dividing the greater by the smaller coefficients; on escaping from the lens into the vitreous humor, they are refracted *slightly from* the perpendicular, according to the relative index of refraction of those two parts. These facts, the varying refractive powers of different portions of the lens, and the not absolutely perfect centring of the several systems of refracting media in the living eye, render it impossible to obtain mathematical exactness as to its dioptric action.

The manner in which the eye, regarded as an optical instrument, corrects the errors or aberrations to which such instruments are liable, is most remarkable.

The density and refractive power of the crystalline lens are gradually diminished towards its borders, so that the tendency to over-refraction in that portion of it is counteracted, and thus, as well as by the aid of the peculiar curves of its two surfaces, *spherical aberration* is probably absolutely corrected. The *dispersion*, or *decomposition* of light in the eye, is very slight; and different and mutually corrective dispersive powers of the cornea, the aqueous humor, and the lens with its capsule, probably correct *chromatic aberration.* It should be added, that the exclusion of the marginal rays by the iris, diminishes the tendency to both the preceding defects. But under certain circumstances, *chromatic* vision, or the perception of colored fringes at the margins of objects, occurs; for example, when the eyes are not correctly accommodated to a near object; also when one-half of the eye is covered by a dark screen. In the latter case, the corrective effect of one-half of the lens on the other half, by its opposite dispersive influence over the rays of light radiating from any given point of the object, no longer takes place.

The errors of *distortion* and *confusion* are likewise diminished by the exclusion of the marginal rays by the iris; but they are not noticeable in vision through the central part of the eye, nor in lateral vision. The error from *curvature* is corrected in the eye by the concave shape of the retina.

The *optic centre* of the eye, is a point in its antero-posterior axis at which the rays of light intersect each other as they cross to produce an image; and the distance between this point and the retina must be adjusted to accommodate vision for objects at different *distances.* If one eye be closed, and the other be turned towards two objects placed one in front of the other, in the same line, and at a certain distance apart, the rays proceeding from the two objects, meeting at different foci, the retina does not receive a distinct impression of either; but *circles of dissipation*, as they are termed, form around the images of the objects. If, however, the eye be directed first to one, and then to the other object, they are both distinctly perceived in succession. In such acts, one is conscious of certain *change and effort within the eye.* When the eyes are directed from a distant to a near object, the change is apparently due to some internal muscular contraction, which ceases the moment distant objects are looked at, the parts then resuming their natural and unconstrained position. The sense of fatigue, which always attends near vision, if long continued, is immediately relieved when the eyes are directed to distant objects, the state most commonly regarded as that proper to the eye when at rest.

Concerning the nature of the changes which the eye undergoes, in its adjustment for different distances, various theories have been advanced. According to one view, the adaptation of the eye to distance is effected by means of changes in the condition of the *iris*, inasmuch as in near vision the pupil is contracted, and in distant vision dilated. The contraction of the pupil, which always takes place when near objects are viewed, may, by excluding the marginal rays, help to prevent the formation of circles of dissipation, and thus to render the images of objects more distinct. On this principle a small object held close to the eye, and therefore seen indistinctly, may be rendered distinct by looking at it through a small pin-hole in a card; this cuts off the marginal rays; at the same time, the object appears less bright, and also magnified, because its image on the retina is larger, owing to its proximity to the eye. The contraction of the pupil is not, however, the sole change that takes place in near vision, and certainly not the efficient change; for on looking at a bright luminous body situated at a great distance, the pupil contracts, whereas if the eye be directed to a near object of feeble luminous power, the pupil dilates. Moreover, the adjustment of the eye can be effected, even when looking through an unchangeable pin-hole in a piece of paper; further, in cases in which the iris is wanting, or in which it has been entirely removed, the power of adaptation of the eye has remained perfect; and lastly, in long-sighted persons, although the pupil may contract with great vigor, yet near objects are very indistinctly seen.

The movements of the iris under the several above-mentioned conditions, seem to be *consentaneous*, being primarily regulated according to the quantity of light entering the eye, which is relatively more intense, from near objects.

The adaptation of the eye to vision at different distances has been referred, by some, to alterations in the distance between the optic centre of the eye and the retina, produced by the *pressure* of the ocular muscles *upon the eyeball.* Thus it was maintained that, in near vision, the antero-posterior diameter of the eyeball is lengthened by the action of these muscles, according to some by the recti, according to others by the oblique muscles. But to be efficient in accommodating the eye to the necessary distances, such elongation or shortening of the eyeball must be greater than can possibly occur in it. Moreover, in cases of paralysis of the recti muscles, the power of accommodation of the eye to distance is not impaired, and it has even been proved that these muscles are unable to produce any appreciable change in the form of the globe. Nor can the adjustment of the eye as regards distance be owing to the action of the oblique muscles; for under the influence of belladonna, not only does the pupil dilate, but the normal adaptive power of the eye is lessened, although the oblique muscles remain unaffected, for the eyes can still perform all the movements dependent on them.

The necessary adjustment has also been attributed to an elongation of the distance between the retina and the optic centre, by a *forward movement of the crystalline lens* as a whole, but such a movement is not known to occur.

This accommodation of the eye has also been ascribed to *changes* in the degree of convexity of the *cornea*, effected by the ocular muscles; and, as the refractive power of this transparent coat, and of the aqueous humor behind it, is so much greater than that of air, a very slight increase in the convexity of the cornea would be sufficient to account for the whole adjusting power of the eye for near objects; but the convexity of the cornea is said to undergo no change, being the same in near as in distant vision. This and the preceding explanation are further opposed by the facts of a case, in which, although there was paralysis of the third nerve, and consequently of all the ocular muscles, excepting the superior oblique and external rectus, the power of accommodation was unimpaired (Von Gräfe).

That some change in the position or form of the crystalline lens is intimately connected with the power of accommodation, is shown by the fact, that when this body is removed, an operation performed when it becomes opaque, constituting the disease known as *cataract*, the power of accommodation is almost wholly lost. It is now, indeed, generally admitted, that the adaptation of the eye to vision at different distances, or the correction in it of *distantial aberration*, is due to changes in the *shape of the lens*, and that, in near vision, the *convexity of its anterior surface becomes much increased*, so that a forward movement of this surface ensues, the convexity of its posterior surface remaining unchanged (Helmholz). If, in a dark room, a lighted candle, or any other luminous body, be held on one side of the eye, at a distance of about 18 inches, the observer, standing on the opposite side to the light, will see three images of the candle; an anterior erect one, reflected from the surface of the cornea, a *middle*, also erect image, reflected from the anterior surface of the crystalline lens; and a posterior inverted one, reflected from the posterior surface of the same. The light and the observer should form an angle of about 20° with the eye examined. The first two images are erect, because the cornea and anterior surface of the lens, are convex reflecting surfaces; the third image is inverted, because the posterior surface of the lens acts as a concave reflector forwards. The anterior erect image is the brightest and the clearest of the three; the middle erect image is the largest, the least defined and the least luminous; the posterior inverted image is the smallest, and intermediate in clearness between the other two.

When the eyes are turned from a distant to a near object, the anterior erect, and the posterior inverted image, undergo no change of position, but the middle erect and least luminous image advances somewhat towards the anterior erect image; at the same time, the pupillary margin of the iris undergoes a slight forward inclination, approaching the cornea. Unless the change just mentioned in the middle image be owing to some other conditions, such as an alteration in the position of the eyeball, or an increase in the convexity of the cornea, either with, or without, a forward and backward movement of the lens, it must be produced by some alteration in the form of the anterior surface of the lens itself. No change in the position of the eyeball, however, is necessary in the act of accommodation; the cornea presents no change in its convexity, such as has been supposed to be produced by the muscles external to the eyeball; any assumed movement of the lens, as a whole, forwards and backwards, is inconsistent with the fact that, according to the best observers, the posterior surface of the lens does not shift its position. The phenomena actually observed can therefore only be explained by supposing that an alteration occurs in the convexity of the anterior surface of the lens.

An instrument named the *ophthalmometer* has been used, to overcome the difficulties of ascertaining and measuring the minute changes in the relative shape and position of the two images of the flame reflected from the anterior and posterior surfaces of the lens, in the experiment just referred to; and many most careful determinations of the actual changes which take place in the lens, in the position of the ciliary processes, and in the condition of the iris, have now been made. An increased convexity of the anterior surface of the lens, a forward movement of this surface, so that it approaches the cornea, and a necessary increase in its antero-posterior axis, have thus been noticed. The radius of its anterior surface is diminished, and its vertex approaches the cornea. In the normal eye, the radius of the curve of the anterior surface of the lens is said to measure 8.8 millimetres in distant vision, and 5.9 in near vision; in the former case, the distance of the anterior surface of the lens from the surface of the cornea is 3.9; in the latter, 3.4 millimetres. The posterior surface of the lens is said to undergo but little, or, according to the best authorities, no change either in shape or position. By some, however, a slight forward movement of the lens is supposed to occur in near vision. During near vision, the pupil contracts, whilst the pupillary margin of the iris moves forwards, and its attached border or rim falls backwards (Helmholz). On this point, however, contrary statements have been made; for the plane of the whole iris is said by Knapp to move forwards $\frac{1}{12}$th of an inch; whilst, according to Czermak, it undergoes no change, remaining perpendicular. It is, moreover, stated that, in near vision, the points of the ciliary processes recede from the margin of the lens (Becker). In accommodation for distant vision, on the other hand, the pupil dilates, the inner border of the iris falls back, and the points of the ciliary processes are said to approach the margins of the lens.

The altered shape of the anterior surface of the lens, now generally admitted to be the essential change in the accommodation of the eye for near vision, is attributed by Helmholz, the originator of these researches, to joint muscular and elastic action; whilst the restoration of the lens to its shape when at rest, is supposed to be due to elasticity alone. According to him, the lens, when at rest within the eyeball, is subjected to the tension of an elastic zone connected with its margin, which maintains its anterior surface somewhat more flattened than it would be if not so acted upon; the elastic zone here spoken of, seems to coincide with the so-called highly elastic suspensory ligament of the lens. When, however, the eye is turned to a near object, the ciliary muscle is supposed to contract, to draw forward the choroid coat, and, with it, the hinder margin of the elastic zone, which is thus relaxed, and so its effect in flattening the lens is counteracted, and the lens, by its own elasticity, becomes more convex in front. According to this view, therefore, the active agent in near accommodation is the *ciliary muscle*, which sets free the elasticity of the lens; and the feeling of effort experienced in such adjustment must be chiefly due to the action of that muscle; whilst distant accommodation involves only the employment of the elastic force of the suspensory ligament of the lens.

Though the explanations of Helmholz are generally accepted, it is maintained by some, that, in near vision, the lens undergoes an alteration both in shape and position, through the influence of the ciliary muscle, or of some simultaneous pressure, exercised by the iris also, upon the margin of the lens. By this pressure, the substance of the lens is supposed to be subjected to the degree of tension necessary to increase its convexity; whilst, in distant vision, the muscular parts are supposed to relax, and the lens, by its own elasticity, to recover its flatter form (H. Müller and Cramer). The swift forward movement of the lens is supposed to be owing to the ciliary muscle drawing forward the choroid coat, which acts on the vitreous humor, and this, in its turn, on the lens. Lastly, an opinion recently entertained, is, that the eye is at rest only when objects situated at medium distances are looked at, and, that, in the production of the changes in the eyeball necessary for near vision, the circular fibres of the iris contract, whilst the radial fibres contract when distant objects are viewed (Langenbeck, Henke). If such be the case, it is difficult to account for the fact, that the sense of fatigue, which, as already mentioned, always attends near vision, immediately disappears on directing the eyes to distant objects. Moreover, on opening the eyes after they have been closed for any length of time, distant objects are those most clearly perceived.

There can be little doubt, however, that, whatever may be the nature of the changes in the lens, by which the necessary adjustment is effected, they are accomplished *chiefly*, as is now generally supposed, by the agency of the fibres of the ciliary muscle, or so-called tensor of the choroid, with which the iris may in some way co-operate. The movements themselves, though instigated by the will, and assisted by sensation, are automatic. As is well known, atropine, the active principle of the atropa belladonna, or deadly nightshade, whether locally applied, or taken internally, dilates the pupil; but it also destroys the power of accommodation of the eye to distances, distinct near vision being rendered impossible. The extract of the Calabar bean, on the other hand, contracts the pupil, and, at the same time, the power of distinct distant vision is diminished, whilst that of near vision is increased; the power of accommodation is not, however, entirely paralyzed. The visible effects of these substances are upon the iris; but it does not follow that they are limited to the muscular fibres of that structure, so that the changes in the accommodating power of the eye produced by them, must not be entirely attributed to the dilatation or contraction of the pupil. There probably occur simultaneous effects on the ciliary muscle, the conjoint results being, not only a change in the size of the pupil, but also in the form of the crystalline lens. Opium is another medicine which contracts the pupil, but its effects on vision do not appear to have been accurately studied. Hydrocyanic acid dilates the pupil widely, the circular rim almost disappearing.

It is not yet understood how these medicinal agents affect the pupil. Atropine, for example, may cause dilatation, either by paralyzing the oculo-motor nerve, or its nervous centre, which might be termed *passive* dilatation, or by stimulating the sympathetic nerve or nervous centre, constituting an *active* form of dilatation, or in both ways simultaneously. But atropine is found to influence the state of the pupil, after division of both the above-named nerves, and even after excision of the eyeball. It is possible that these agents affect the pupil only indirectly, by their blunting, or exalting, the sensibility of the retina, and so causing, in the former case, dilatation, in the latter, contraction, of the pupil.

The accommodation of the eye in viewing near objects, is known as *positive* accommodation, that in looking at distant objects, as *negative* accommodation. The act of accommodation is effected more rapidly, when the eye is turned from a near to a distant object, than when it is directed from a distant to a near one. The time required is probably modified by age, practice, and other circumstances; in old age, for example, more time is occupied in accommodating the eye for near objects, than in childhood. The accommodation, when the eye is turned from an object at 60 feet distance, to one at $4\frac{1}{2}$ inches, is said to take place in $\frac{9}{10}$ths of a second; whereas only $\frac{7}{10}$ths of a second elapse in changing the accommodation from $4\frac{1}{2}$ inches to 60 feet (Vierordt). It would seem, however, that, in the case of short distances, the time necessary is relatively much greater; for according to other observations, the accommodation from 17 inches to $4\frac{1}{2}$ inches, requires as long as 2 seconds: that from $4\frac{1}{2}$ to 17 inches, $1\frac{1}{5}$th of a second (Aby). Between a distance of 200 feet and the horizon, all objects are seen equally clearly without change of accommodation; but at nearer distances, the necessity for exact accommodation increases, and, in very near vision, it is absolutely essential, one object only in the so-called *line of accommodation* (Czermak), being clearly visible at the same time.

The range of healthy vision, or the sight of *hemitropic* eyes (Donders), is limited by two points, named the *far point*, or point of rest, and the *near point;* the ordinary limits of near vision, or close focal adjustment, and of distant vision, are said to be from about five inches to indefinite distances, according to the intensity of the light. The ordinary focal distance for easy, clear vision, as in reading, is about eight inches. But the proximity of the near point is greater in early life, and afterwards progressively diminishes. Thus, at the 10th year, it is only $2\frac{2}{3}$ of an inch in front of the cornea; at each succeeding decennial period, its distance is $3\frac{5}{9}$, $4\frac{4}{5}$, $6\frac{6}{7}$, 12 and 24, till at the 70th year, its distance from the front of the cornea is 144 inches (Fellenberg). The far point may be said to have no limits. Under the action of atropine, the near point recedes, and gradually reaches the far point. The Calabar bean lessens the distance of the far point, and frequently also that of the near point.

In certain persons, the natural range of adaptation of the eye to distance is defective, and exceedingly limited, so that they are unable to see objects except at certain distances. Such persons are either *short* or *long-sighted*. In long sight, objects are only seen distinctly when at a distance from the eye; near objects, if small, are either invisible, or else only confused images of them are perceptible. In short sight, on the other hand, objects at a moderate distance are invisible or indistinct, the power of distinct vision being limited to objects brought very close to the eye; at the same time, a short-sighted person sees small and near objects very distinctly, better illuminated, and under larger visual angles, and therefore larger and brighter, than other persons.

These abnormal conditions of vision arise from a certain fundamental excess or defect in the refractive power of the eye. In long sight, for example, the cornea is flatter than usual, and the antero-posterior diameter, or optic axis, of the eye is said to be lengthened; the rays of light do not undergo sufficient refraction, but, instead, converge to a focus *behind* the retina; by the use of convex glasses, the convergence of the rays is increased, and they are brought to a focus upon the retina. In short sight, the convexity of the cornea is too great, so that the rays proceeding from an object, instead of being brought to a focus on the retina, intersect each other at a point *in front* of that membrane; the antero-posterior diameter of the eye is also probably shortened; this defect is corrected by wearing concave spectacles, which cause divergence of the rays, so that the overconvergent effect is counteracted, and the rays are brought to a focus upon the retina. It is probable that not only the curvature of the cornea, but that of the lens also, is peculiar, both in long and short sight. In both conditions, not only are the images thrown on the retina indistinct, but luminous circles of dissipation are formed upon it. Short-sighted eyes often improve by age, the cornea being said then to become flatter, owing to a diminution in the quantity of the fluids of the eyes. Normal eyes, from the same cause, may become long-sighted in old age.

To determine with accuracy the focal distance of the eyes, various instruments, named *optometers*, have been invented. A simple plan, devised by Scheiner, is to make two holes with a needle in a card, the distance between which must be less than that between the two pupils.

On now looking at a perpendicular line, through these holes, the line appears double if the eyes be too close to it, but single at the distance of perfect or normal vision, which distance is thus ascertained for any particular eyes. It is desirable in the selection of glasses, not to over-correct the natural defect, for this would fatigue and weaken the eyes still more. The eyeglass, or spectacles, should merely render objects distinct, but not magnify or diminish them. Concave glasses are numbered according to the distance of their virtual focus from them. By multiplying the normal distance of near vision, say 10 inches, by the distance of clear vision in the short-sighted person, say 4 inches, and dividing the product by the difference between those two factors, the number of the concave glass required is found; thus, $10 \times 4 \div 6 = 6.6$; *i. e.*, about No. 7 glass. The same rule obtains in the choice of convex glasses for long-sighted people. In the normal eye, concave glasses diminish the size of objects looked at through them, because they diminish the actual size of the retinal image. On the other hand, convex glasses, or lenses, including both simple and compound microscopes, increase the apparent size of objects, by enlarging their images on the retina; they, in fact, enable the eye to see such objects under large angles, or as if they were very closely approximated to the eye. The necessary dilution of the light, in this process, is met by various contrivances for powerful artificial illumination.

A distinction has been drawn between *short* and *long* sight, or so-called *myopia* and *presbyopia*, on the one hand, and *near* and *far* sight, or *true myopia* and *presbyopia*, on the other. The former states depend, as we have seen, on individual peculiarities in the *shape* of the eyeball or its parts; for, besides normally-constructed eyes, there are eyes, the natural foci of which lie either in front of the retina, helping the eye in near vision, or behind the retina, adapting it for distant vision. The causes may be a greater or less prominence of the cornea, a shorter or longer optic axis, and a greater or less curvature of the lens. Near sight and far sight depend on defects in the *power of accommodation* of the eye; as, for example, on loss of power in the ciliary muscle and iris, or on diminution of the elasticity of the lens or its suspensory ligament, both of which conditions are found in advancing age. In short sight, the point of nearest vision may be even as close as two inches to the eye; but in near sight, or true myopia, the near point may be 12, 30, or even more inches from the eye. The term *hypermetropia* has been used to designate the condition of long sight, sometimes named presbyopia, which latter term is then restricted to the impairment of vision, as regards near objects, which comes on after a certain period of life, and which is due to a diminution in the range of the power of accommodation (Donders.)

In many individuals, the focal lengths of the two eyes are different, a fact which escapes attention, unless the difference be very marked. It is worthy of observation that short-sighted eyes are still *achromatic*, objects seen indistinctly by them being without colored fringes. According to Ehrenberg, the absolute limits of vision are in no way dependent on the focal distance of the eyes, and in individuals possessing ordinary visual powers, present but slight differences.

In some persons, the refractive power of the horizontal and vertical meridians of the eye is unequal. This condition, which is not uncommon, is known as *astigmatism.* It is due to a difference in the degree of convexity of the cornea or crystalline lens, or of both these parts, in the horizontal and vertical directions, so that corresponding rays passing into the eye, instead of converging to one identical point, meet at two different foci. By means of cylindrical glasses, this imperfection can be corrected.

The *dilatation* and *contraction of the pupil*, which result from variations of light, are purely reflex phenomena. The sensory fibres of the iris, as well as its vasi-motor fibres, are derived from the fifth cranial nerve; irritation of either the first or second divisions of this nerve, causes the pupil to contract on the same side.

The direct effects of heat and light on the iris, in dead animals, have been noticed by Brown-Séquard. If the eye of a rabbit, or other animal, be subjected, shortly after death, to a sudden elevation of temperature of from 50° to 60°, the pupil, if previously contracted, dilates, or, if dilated, it contracts; these effects are explained by supposing that the heat acts more powerfully on those muscular fibres which had previously been at rest. Light causes contraction of the pupil in Mammalia and Birds, for a short time after death; but in eels and frogs, the iris may be so excited even sixteen days after! Yellow light seems to act the most powerfully. This sort of contraction can be induced after removal of the posterior half of the eyeball, so that it cannot be referred to reflex action.

During life, the diameter of the pupil diminishes with increasing light, the amount of contraction being proportionate to the strength and duration of the luminous impression. A direct light acts more powerfully than a slanting light, the sides of the retina being apparently less excitable. When the two pupils are under the influence of different degrees of light, they are still usually of equal size, unless the difference of luminosity be very great. If one eye only be acted upon by light, both pupils contract, the one not exposed to the stimulus rather less than the other. Contraction of the pupil takes place more rapidly than dilatation; and it has further been noticed that the movements of the iris are quicker than those of other parts composed of unstriped muscular fibres. Excessive dilatation of the pupil is named *mydriasis*, and excessive contraction, *myosis.*

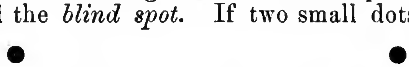
The chief object of these changes in the size of the pupil, is to regulate the quantity of light admitted to the eye, and to protect it against too dazzling luminous rays; they also, in this way, determine the brightness of the retinal images, which become brighter as the pupil dilates, though they may be then less defined or distinct.

As already mentioned, during near vision a consentaneous contraction of the pupil occurs. It has been noticed, indeed, that the pupils also contract when the eyes are made to converge, and, as this convergence always accompanies the act of looking at near objects after distant ones, this likewise aids in inducing the contraction of the pupils necessary for near vision. It is through the oculo-motor nerve, which supplies the sphincter of the pupil as well as the internal recti muscles, that this consentaneous narrowing of the pupil is excited. But the one movement is independent of the other, because the contraction of the iris, and the accommodation movements, occur equally well, when one eye only is used; and, by some persons, the eye can be accommodated without any change in the degree of convergence. Lastly, certain cases have been recorded in which the movements of the iris were, in some manner, perhaps indirectly, under the control of the will.

The movements of the ciliary muscle, like those of the iris, with which they appear to be consentaneous, are usually involuntary; they are probably, however, sometimes independent of each other. The nerves which regulate the action of the ciliary muscles are supposed to be branches of the third pair, but this is uncertain. In some exceptional cases, the ciliary muscle has exhibited an apparent subjection to the control of the will.

The nervous centres concerned, are the anterior pair of the corpora quadrigemina; the afferent nerves are the optic nerves; and the efferent nerves are the third cranial, and the sympathetic. The dilatation of the pupil is regulated by nervous influence, conveyed from the spinal cord, through the branches of the sympathetic nerve, which supply the radiating fibres, division of that nerve in the neck being followed by contraction of the pupil, and its irritation by dilatation. The contraction of the pupil is governed by the circular fibres, and is regulated through the third cranial nerve alone. Irritation of the latter nerve causes narrowing, whilst its division is followed by dilatation of the pupil. The diameter of the pupil at any particular moment, however, depends on certain combinations of action of its radial and circular fibres. Its state of complete repose, or quiescent condition, as, for example, when no light is present, or the optic nerves are diseased or inactive, is that of moderate dilatation. After division of the optic nerve, in an experiment, the same result is noticed; if then, the third cranial, or oculo-motor nerve, which supplies the circular fibres, be divided, the pupil does not widen; but if the sympathetic, which supplies the radial fibres, be now cut, the pupil slightly contracts. From this it would seem, that in moderate contraction, only the radial fibres are really active.

Of the different portions of the *retina*, the fovea centralis, which is situated in the line of direct vision, is the part most sensitive to light, and is the seat or area of *distinct vision*, both as regards form and color. At the point of entrance of the optic nerve, the optic colliculis, or optic eminence, which is not in the line of most perfect vision, the retina is incapable of receiving distinct visual impressions. It has indeed been named the *blind spot*. If two small dots be made upon a



piece of paper, at a short distance from each other, and the optic axis of the right eye be directed vertically upon the left-hand dot, whilst the left eye is closed, it will be found, that when the paper is held about four times as far from the eye as the dots are from each other, the right-hand dot will be no longer visible, for its image falls upon the optic eminence. In the same manner, when the image of an object is made, by artificial means, to fall simultaneously upon both optic eminences, no visual impressions are excited by it. Since this portion of the retina, which is thus deficient in sensibility to light, consists only of the diverging fibres of the optic nerve, all the other elements of the retina being absent, whilst that portion of the retina most sensitive to light, viz., the fovea centralis, is destitute of all the retinal elements, except the cones and gray ganglionic nerve vesicles, it would seem that the optic nerve fibres are excited only by the changes induced by luminous rays in some other retinal structures, and are themselves only indirectly excitable by light. The rods and cones alone appear to be the proper recipient organs. The yellow spot, the part most sensitive to light, contains closely-packed cones and ganglionic cells, but is destitute of nerve fibres; whilst at the sides and anterior parts of the retina, the rods become less numerous, and the sensibility to light is diminished. Moreover, exposure of the optic nerve itself to the strongest light, gives rise to no luminous sensations, and excites no reflex contractions of the iris; besides this, in the eyes of insects, as we shall hereafter describe, the rods and cones only are exposed to the action of light, the optic nerve fibres being covered by pigment. The rods and cones, or perhaps even their outer and more highly refractive segments only, may, indeed, be regarded as the parts which receive the undulatory movements of the luminiferous ether, and modify, or *translate* them, into nervous energy or force, which then manifests itself, by propagation along certain of the radial nuclear fibres to the ganglionic nerve cells, thence to the plexiform fibres of the retina, through these to the optic nerves and tracts, and finally to the optic sensorial centres.

It may here be remarked that, whilst the parallel *cochlear* elements, the rods of Corti, receive the sonorous impulses at right angles to their own direction, the parallel *retinal* elements, the rods and cones, receive the luminous rays in lines corresponding with their own direction. This difference may be connected with the condition, already adverted to, viz., that the supposed movements of the luminiferous ether are transverse to the direction of the imaginary lines called rays, whilst, as is well known, the movements which produce sound, take place in the direction of the sonorous rays. In both the ear and the eye, therefore, the microscopic recipient organs, connected with the extremities of the nerves, are so arranged, that their proper exciting *motions* do not pass inoperatively *between* them, but agitate them *transversely*.

In the retina of Man and of the Vertebrata, all the light must pass through the nerve-fibres, ganglionic cells, and bloodvessels, and also through the granular layer, before it reaches the rods and cones, or true excitable elements. The existence of these last-named structures appears indispensable to distinct vision; their outer free ends form a mosaic surface, on which local points of light fall evenly, and thus excite the sensation of a uniform visual field, having definite points of *locality*, which would be impossible if the light directly stimulated the plexiform nerve-fibres; for, in that case, the same fibre would receive numerous luminous impressions along successive points of its course, and so would be excited, without an exact localization of the sensory impressions. The position of the rods and cones perpendicularly, or nearly so, to the retinal surface, evidently adapts them for the distinct reception of local points of light, for which purpose the lateral surfaces of the linearly-expanded optic fibres are ill suited. Beyond the rods and cones, is placed the dark choroid coat, the pigment of which is supposed incessantly to absorb the light which passes through, so as to prevent confusion from successive impressions. In Albinos, in whom this black pigment is wanting, vision is imperfect, especially in strong lights, which may even cause pain.

[Professor Draper,* of New York city, has recently revived and developed the theory held by some early optical writers, but long since abandoned, that the black pigment of the choroid coat is the receiving screen for the image. His arguments, based upon optical and anatomical grounds, are well founded, and apparently unanswerable. In the first place, the retina, during life, is a perfectly transparent medium, and therefore as incapable of receiving an image as is a sheet of transparent glass or the atmosphere itself. But the black pigment, by completely absorbing the rays, not only prevents indistinctness, by preventing reflection, but also converts the rays into heat. It is well known that an essential condition of perfect vision requires that images should form on a mathematical superficies, and not in the midst of a transparent medium; a condition supplied by the black pigment and not by the retina.

By considering the retina in radial section, as recommended by H. Müller, it appears that the four strata composing it—1st, Jacob's layer of rods and cones; 2d, The granular layer; 3d, The vesicular layer; 4th, The fibres of the optic nerve—are really connected in such a way that, passing in a radial direction, as respects the globe of the eye, these different elements are successively combined to constitute the "radiated fibre system." That is, from each of the proper fibres of the optic nerve, going from within outwards, passes a thread-like body, including, successively, a vesicle, a granule, a cone, and terminating in a rod; keeping up, in this way, through the thickness of the retina, a continuous nervous communication from the extremity of the rod to the fibres of the optic nerve, so that the true termination of each fibre is therefore a rod. According to Müller and Kölliker, the rods and cones of Jacob's membrane are the true percipients of light, communicating their condition to the fibres of the optic nerve, by means of the connection which they thus maintain with it; or, perhaps, as stated by Dr. Draper, "the rods and cones are conductors of the luminous impression to the nerve-cells of the retina, which consti-

* Human Physiology, by J. W. Draper, M.D.

tute a ganglion capable of perceiving light, and the fibres of the optic nerve merely communicate these impressions to the sensorium."

According to either description, the essential point maintained by Draper is, that the sentient or receiving part of the retina, is the posterior; that which is in contact with the black pigment or receiving screen, whence the impression is taken. In accordance with this explanation, the same thing occurs, though with infinitely more delicacy, in the eye, as when we pass the tip of the finger over the surfaces of bodies, and recognize on them warm and cold spaces. "The club-shaped particles of Jacob's membrane, are truly tactile organs, which communicate to the surface of the retina the conditions of temperature of the black pigment." This is confirmed by the fact that, at the point where the optic nerve enters the eye, and where only the fibrous elements of the retina are present, there is no vision.

Moreover, according to Dr. Draper, "If no other argument was adduced for departing from the opinion usually expressed, which attributes this function to the retina, the thickness of that structure would be sufficient; images can only form with precision or sharpness upon an abrupt surface. And since it is now indisputably ascertained that both the chemical effect and heating effect of the rays of light depend on their absorption, those effects being in direct proportion to the completeness with which absorption is taking place, we are justified in inferring that, since the eye is sensible to rays of so low a degree of intensity, and to each of the colored ones equally, its screen of reception must not only be a superficies, but likewise a black one. Such a surface the black pigment is. In the case of Albinos, and animals in which the black pigment is imperfectly developed, the receiving surface or screen is still the interior of the choroid. Under such circumstances vision must be indistinct."

It accords also with facts in the diffuse sensibility of some of the lower orders of animals to light, and in the structure of the ocelli, "to consider that the primary effect of rays of light upon the black pigment is to raise its temperature, and this to a degree in relation to their intensity and intrinsic color; light which is of a yellow tint exciting most energetic action, and rays corresponding to the extreme red and the extreme violet the feeblest. The varied images of external objects which are thus painted upon the black pigment, raise its temperature in becoming extinguished, and that in the order of their brilliancy and color; the pigment thus discharging a double duty, as a surface of extreme sensibility for calorific impressions, and also as darkening the interior of the globe."

Again, it is necessary, in order that a perfect image may be formed, that the luminous body should possess an inherent degree of heat of at least 1000°, for rays from a source having a lower temperature, cannot pass through a stratum of water or the humors of the eye. The eye is different from the thermometer in this, that while the latter is sensible to rays of every sort, the eye is not; the necessary presence of absorbent media stopping all rays of low refrangibility.

Professor Draper, carrying out, through a series of years, experiments instituted by Count Rumford many years ago, has concluded that all photographic effects are the effects of a high temperature. "The impingement of a ray of light, on a point, raises the temperature of that point to the same degree as that possessed by the source from which the ray comes, but an immediate descent takes place through conduction to the neighboring particles. This conducted heat, by reason of its indefinitely lower intensity, ceases to have any chemical effect, and hence photographic images are perfectly sharp on their edges. It may be demonstrated that the same thing takes place in vision, and in this respect it might almost be said that vision is a photographic effect, the receiving surface being a mathematical superficies, acting under the preceding condition. All objects will, therefore, be definite and sharply defined upon it, nor can there be anything like a lateral spreading. If vision took place in the retina, as a receiving medium, all objects would be nebulous on the edges."

The large amount of blood distributed to the choroid coat, and its proximity to the retina, also render it probable that the former, and not the retina, becomes the receiving screen. Supposing the retina typically composed of three transparent layers, one of tubules, one of vesicles, and one of granules,—the luminous beams pass through them just as through the atmosphere. The vesicular layer undergoes rapid metamorphosis, the effect of which is transmitted by the tubular layer, while in the granular layer lie the germs whence the vesicular layer can be easily redeveloped. But the waste of the vesicular layer cannot occur except under the oxidizing influence of the arterial blood, nor can the nutrition of the granular layer be accomplished without a similar condition. Both are supplied by the construction and proximity of the choroid coat; and the analogy to the skin, both as to waste and restoration, is still kept up.

F. G. S.]

The existence of the so-called blind spot in the retina, does not produce any obvious defect of vision, when both eyes are used, because the image of an object falling on the optic eminence of one eye, naturally falls elsewhere, and on a sensitive part of the retina, in the other eye; and so the blank in vision is filled. In the use of one eye, the defect is partly remedied by the phenomena known as *irradiation*, hereafter to be explained, and partly by our experience and knowledge of the actual forms of objects; furthermore, any impairment of sight, dependent on the existence of the blind spot, occurs beyond the area of distinct vision, and therefore attracts less attention than it would otherwise do, and is more easily corrected by experience, or by the effects of irradiation. If the fibres of the optic nerve, at the blind spot, were directly sensitive to light, then they would receive at least two impressions—one from their retinal extremities, and the other from the light falling on the optic eminence; such a condition would lead to confused vision.

Müller and other physiologists, however, have denied that the retina at the point of entrance of the optic nerve is wholly insensible to light. They believe that the excitability of the retina is there peculiarly diminished, but that it exhibits, in a marked degree, the phenomenon of irradiation. The vanishing of the dark image of the dot, in the experiment above mentioned, was referred by Müller, to a power in the retina, of communicating to a smaller portion, a condition affecting a larger part. Thus, when the retina is exposed to two different impressions, one of which falls upon a larger, the other upon a smaller portion of the membrane, the former impression is, after a time, propagated to the whole of the surface, whilst the latter is no longer perceptible. If, for example, one eye be directed, for a certain time, upon a narrow slip of colored paper fixed upon a white ground —after a brief interval, the image of the former vanishes, the white ground alone being visible; this is most marked, when the lateral portions of the retina receive the image (Purkinje and Brewster).

In the exercise of the senses of touch, taste, and smell, we refer the sensations excited, to the organ, or part, of the body where the stimulus acts on the extremities of the nerves; but, as in hearing, so in sight, the sensations are rapidly converted into *perceptions*, and are referred, though far more definitely, altogether to the exterior, and, in the exercise of sight, actually to the external objects from which the rays of light are given. The images formed on the retina, are never referred by the mind, to the interior of the eye, where their existence is not known to the untaught mind, and where, even when informed of the fact, the mind is still unconscious of their presence.

This *outward projection* of our visual sensations, is, by some, regarded as an ultimate fact incapable of explanation; but others believe that it depends upon experience, gained by comparing the results of vision, as regards our own bodies and external objects, with the concomitant results afforded by the sense of touch, aided by movements of the body. Vision, considered as a means of obtaining a knowledge of the presence, form, color, position, and motion, of external objects, is wholly dependent upon this outward projection of its impressions. Even in excitement of the retina by pressure, electric shocks, or internal stimuli, the luminous impressions produced, are referred to the exterior.

The perception of objects in their *erect position*, through the agency of an inverted image, is intimately connected with this outward projection of vision. The mind, in referring the luminous impressions in the sensorium, to the objects whence the rays of light proceed, follows these latter, as it were, from the retinal image, and views their several focal points in the direction of certain imaginary lines, which are more or less nearly perpendicular to the retinal surface. It has been shown by Serre, in his experiments on the luminous spectra, produced by pressure on the eyeball, and called by him *phosphènes*, that visual impressions are projected from the retina, along certain lines, towards a common centre in the eyeball, or *optic centre*, which he calls the *centre of direction*, and which he locates in the middle of the crystalline lens. Others, however, have variously supposed that these lines, which they name *lines of direction*, meet in front of the lens, in the centre of the pupil, or, behind it, in the centre of the eyeball. Having crossed each other at the optic centre, these lines emerge from the refracting media of the eye, suffer a slight change in their course, pass outwards to the object, and correspond with the direction in which the central ray of each luminous pencil (Fig. 83) reaches the eye, as it proceeds from the object to the retina. In applying this theory to the explanation of the problem of erect vision from an inverted image, it is supposed that every point of the object (of the arrow, for example) being seen along these lines of visual direction, appears to the mind in its true position in space, and that hence the entire object is perceived *erect*. According to Müller, however, images of objects formed on the retina, may really be *perceived* by the mind in their *inverted* position, but as all objects, including the body and limbs themselves, are thus seen inverted, their relation to each other remains unaltered, and we should be ignorant of this inversion, were we unacquainted with the laws of optics. Some have supposed that the sense of touch corrects a primitive error of ocular observation, or of perception, in the infant; but to this it may be replied, that the one sense is always in harmony with the other, the image of the hand being inverted, and thrown upon the same part of the retina, as the image of the object to which it is directed. Moreover, it is obvious that the general sense of locality or position of the body, gives rise to the notions and terms, upper and lower, above and below, right and left, and so we regard things as erect or inverted, according to their position in relation to that of our own body. In this way also, we know that to look at something above us, we must turn our head or eyes upwards, and such a movement, not the position of the retinal image, which is unknown to us, determines our notion or judgment of the position in space, in which the object lies as regards our body.

The area of outward visual projection, is named the *field of vision;* its horizontal and vertical measurements have been differently estimated at from 116° to 120° and from 130° to 180° of a circle respectively. Its greater horizontal diameter is owing to the two eyes being concerned in its production. The horizontal diameter is not constant, but diminishes in convergence of the two eyes. Lines, drawn from the upper and lower, and from the lateral boundaries of this area, to the optic centre of the eye, form angles at that point; when prolonged backwards to the retina, they also form similar angles. These are the optic or *visual angles* of the field of vision.

The only part of the field in which vision is perfectly distinct, is a small surface, the centre of which corresponds with the hinder end of a line drawn from the yellow spot to the centre of the cornea, *i. e.*, along the visual, or optic axis of the eye. The *area* of the retinal surface which is best fitted for *distinct vision*, is about $\frac{1}{3}$ or $\frac{1}{2}$ of a line in diameter; this corresponds with the breadth of the yellow spot. Around this, is a small circular portion of the retina, known as the *circle of indirect vision*, and beyond that area, vision becomes less distinct, in proportion to the distance of the retinal image from it. The circle of indirect vision is said to be increased during near vision. We can see distinctly, at one time, about six or eight letters of ordinary type; but the lines immediately above and below, are indistinct. Objects, the images of which are situated at an angle of 50° or 60°

from the axis of vision, are seen only in their general outline, while smaller and darker objects may be invisible. The *actual* images on the retina are, however, equally clear at all parts of that membrane, and hence the diminution in the distinctness of vision, must proceed from deficient receptivity of its lateral parts. This is observable in regard to color as well as form. It is said that the retinal sensibility diminishes more quickly in the upward and downward directions than laterally. The existence of a limited area in the retina, specially set apart for distinct vision, enables us to concentrate our attention upon special objects in the visual field, undisturbed by the simultaneous images of surrounding objects. Moreover, by this arrangement alone, we are able to direct the optic axes of the eyes in exact and known directions, so as to gain a knowledge of the direction or position of visible objects, and, further, to adjust the axes of the two eyes, so that they shall meet in any given object, a condition essential, as will be presently explained, for the occurrence of single vision with two eyes.

The *adjustment of the optic* axes upon any object, is accomplished by the movements of the body and head, and especially by those of the eyeballs themselves, which are very rapid, singularly free, and perfectly under the control of the will, the globe of the eye turning, like a sphere, upon its poles or axes, as it rests, in its capsule, on its smooth cushion of fat. By means of the complex movements of the two eyeballs, already described (p. 422), the field of vision of each eye, and that of the two combined, is perfectly under our command, so that the optic axes can be made to converge, with the most extreme accuracy, upon the smallest object which we can see distinctly. This is effected voluntarily, not, however, as a simple direct act of the will upon the ocular movements, but only indirectly, by the mind seeking, through the eyes, the desired attainment of the distinct vision of any given object. The mind, however, is cognizant, through the muscular sensations, that the desired act is performed, and that the position of the eye is duly adjusted. The combination of harmonious movements of the *two eyes*, is beyond our direct control, and is perhaps provided for by a commissural, or other, disposition of the governing nerve-fibres of both eyes, in the oculo-motor nervous centres. As already mentioned, the direction of objects is referred to their correspondence with, or deviation from, the position of the optic axes; and every retinal impression is referred to its proper line of direction in the outer world. The position of these axes is known to us very accurately, by means of impressions, conveyed through the muscular sense, of the condition of the several muscles of the eyeball. The notion of the *direction* of objects, is therefore not a simple sensation, but the result of a judgment, formed by the mind, from certain impressions conveyed to it.

The *apparent magnitude* of an object, is determined by the size of its retinal image, in other words, by the size of its visual angles, or angles formed in the eye, by lines drawn from its extremities or margins through the optic centre of the eye. When the visual angle of an object is known, the object is said to subtend such an angle. The apparent magnitude of an object, is influenced by its distance from the eye, for the angle it subtends must, of course, be larger, the closer its proximity to the eye. The apparent magnitudes of a small object, close to the eye, and of a large object at a distance, such as a pin and a man, are identical, if they subtend equal angles. The degree of movement of the eyeballs, required to pass from one end of the object to the other, is also a further means of determining apparent magnitudes. The sense of magnitude is more exact in regard to horizontal than to perpendicular lines. It is said to be possible to distinguish between two lines of different lengths, even after certain intervals of time, for example, to the extent of a difference of $\frac{1}{40}$th after the lapse of 3 seconds, and of $\frac{1}{11}$th after 70 seconds. The accordance of the senses of sight and touch, as regards the information which they respectively afford, concerning the size of objects, seems to be the result of experience and comparison; for a person born blind, who gained sight by an operation, has been said to state that objects known to him by touch, appeared larger than he expected.

Our knowledge of the *real* magnitude, or *absolute* size, of objects, is only arrived at indirectly, or by means of experience or inference, by comparing them with objects, with the dimensions of which we are already familiar, and by taking into account their respective distances.

In the same manner, our visual sensations inform us only of the apparent or superficial shape and color of objects, of their apparent direction or position in the field of vision, and of their apparent motion in the same. All our conclusions as to their *real* form, color, position, and motion, are arrived at by observation and comparison of these appearances. For the determination of the apparent qualities of any object, and also of its real size and color, *one eye* alone suffices; but for the purpose of ascertaining, by means of the sight alone, its *real form*, *real position*, and *real motion*, the conjoined use of *both eyes* affords material assistance. In this constant mode of employing the two eyes, their distance from each other, named the *inter-ocular distance*, is of the highest optical importance.

We derive our notions of the *solidity*, *roundness*, or *relief* of objects, from the combined use of the two eyes; for when one eye alone is employed, we can only see plane figures having two dimensions, viz., length and breadth. For the perception of solid forms of three dimensions, viz., length, breadth, and thickness, within a moderate distance, the optic axis of the two eyes are made to converge, so that straight lines prolonged from them would meet in the object.

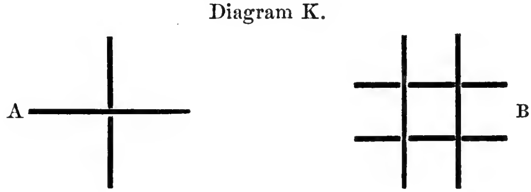
As a rule, an external object forms but a single image in one eye, and the mind, perceiving such single image, refers it to a single object. But there are conditions in which one eye may receive two or more identical images, from, and of, one external object, and then, unless the mind be otherwise informed of the illusion, such images are referred by it to as many distinct, though exactly similar objects. For example, if we look with one eye at a pin through two minute holes in a card, the distance between which is less than the diameter of the pupil, the same retina receives, on different parts of its surface, two separate images of the pin, which, accordingly, being outwardly projected along the proper lines of direction, are seen double, though we know the pin to be single. So, likewise, in the use of the doubly refracting Iceland spar, and of multiplying-glasses or reflectors, the pencils of luminous rays from one object, are so refracted or reflected, as to form double, or multiple images, which are thrown on to different parts of the same retina, and accordingly are seen as multiple images, though known, on other grounds, to proceed from one object.

Each retina regards as single, an image formed on any one definite point of its surface; but single objects necessarily form an image in *both* eyes, and hence, for the useful and undeceptive application of vision, the mind must be able to combine the impressions made by these two images, so as not to be deceived into a belief that they proceed from two objects, instead of from one.

When both eyes are thus directed to any given object, lines prolonged from their optic axes, meet at that object, and the two retinal images produced by it, viz., that formed in the right eye and that formed in the left, fall exactly on the centres of the two retinæ. The images of all surrounding objects are received on surrounding portions of the two retinal surfaces. Those portions, like the central points themselves, are said to *correspond*, though of course, from the complete inversion of the pictures, they are on opposite sides of the centres of the retinæ. The two pictures thus received, are not seen *separately*, and referred to two sets of objects, but are *combined by the mind*, and referred to a single set of objects. In other words, *single vision with two eyes*, results. Sometimes, however, impressions made on the two retinæ are not combined, but are separately distinguished by the mind, producing the phenomenon called *double vision.* It is probable that in the infant, double vision, and, therefore, indistinct vision, is, at first, the rule, but that, by degrees, the eyes are brought to converge suitably on external objects, and thus single vision occurs. By habit and education, this power is, at length, so confirmed, that we are no longer conscious of perceiving two images, but only experience a singleness of perception. When double vision occurs, it is found that the two eyes are not turned directly towards a given object, so that lines prolonged from their axes no longer meet in that object, and the images of it, formed in the two eyes, are no longer received on corresponding points of the retinæ.

These *corresponding* or *identical points* of the retinæ, are, by some, regarded as the result of use or habit alone; but, on the other hand, their existence, as fundamentally or primitively identical spots, is thought to be proved by the following experiments. If pressure be made, in the dark, or when the eyelids are closed, upon the upper portion of both eyeballs, a *single* luminous circle, named *a phosphène* (Serre), is perceived in the centre of the field of vision below. If the lower part of *both* eyeballs be pressed upon, a *single* luminous circle is perceived in the centre of the field of vision above. Hence the upper portions and the lower portions of the two retinæ, are regarded, respectively, as identical. Pressure upon the inner side of one eyeball and the outer side of the other, produces a *single* circle of light, in a direction opposite to that of the pressure; hence the *inner* side of one retina is said to correspond with the *outer* side of the other. But if pressure be made upon the upper part of one eyeball, and the lower part of the other, *two* luminous circles are seen, one above, the other below; in the same manner, pressure upon the inner sides of the two eyes, produces *two* circles, and so also does pressure upon the outer sides. The upper part of one retina, and the lower part of the other, their inner sides and their outer sides, are said therefore *not* to be identical. Speaking generally, those parts of the two retinæ are identical which correspond in situation, in reference to the centre of the eye; thus, the upper portions, the lower portions, the right sides and the left sides, corresponding in this relative position, are identical in sensation. Hence, it has been said that all points of the two retinæ, situated at equal distances from their centres, and lying in the same direction, are identical in sensation, and, when simultaneously excited to action, give rise to the perception of one object. That a general identity of action, or function, of certain parts of the two retinæ, exists, is sufficiently obvious; but that it does not afford the ultimate explanation of the combination of the two images, is shown by the fact that, in stereoscopic vision, as we shall presently explain, the two perspective views of a given solid object, which are necessarily dissimilar, or they would not yield a stereoscopic effect, cannot cover exactly identical parts of the two retinæ, and yet they are combined into one image or impression. Again, images formed on corresponding points of the two retinæ, are sometimes not combined, but are seen double in the visual field, as when we look at one of two objects placed exactly in front of us, between the eyes, the images of the one which is seen double falling nevertheless on exactly identical points of the two retinæ. The same is the case, when we look at one object with both eyes, but through different colored pieces of glass.

Diagram K.



It has been shown by Helmholz, that, in double vision, it is not actually vertical meridian lines on the retinæ which correspond, or are identical, but other lines inclined about $1\frac{1}{4}°$ from the meridian, which he calls *apparently vertical* meridian lines. The horizontal corresponding lines are, on the contrary, actually horizontal. If, for example, as in Diagram K, A, across a horizontal line, another be drawn, accurately perpendicular to it, the right upper included angle appears larger than a right angle to the right eye, and less than a right angle to the left eye; the lower angles are altered in the reverse manner. Again, if two figures be drawn, having similar horizontal lines, but crossed by vertical lines inclined at their upper ends, $1\frac{1}{4}°$ left and right, from a central perpendicular, then, when the left-hand figure (Diagram K, B) is looked at with the left eye only, the angles formed by the vertical and horizontal lines appear to be right angles; but, when looked at with the right eye only, they appear to deviate from right angles, and *vice versâ* with the opposite figure. Two such figures, however, combine stereoscopically, and then make an impression on the mind, of a figure composed of *perfect squares*. In the act of adjustment necessary for this, not only must the eyes be made to converge, by being rotated on their vertical axes by the internal recti muscles, but the oblique muscles must slightly rotate the balls of the eyes on their antero-posterior, or visual, axes (see p. 421).

That the convergence of both optic axes at a given object, is essential for single vision, is proved by the following curious experiment. If two small balls be placed near the further ends of two tubes, it will be found, on looking through the tubes with both eyes, that when the balls are brought nearer to the eyes, and these latter are made to converge, the two eyes receive the impression of a single ball. Each eye realizes its own image of one of the two balls; but the mind is conscious that each image occupies a certain point in space, and these points being *felt*, through the muscular sense of the convergence, to coincide, we judge that one body only can occupy the same point of space at one time. From this experiment, it would seem, that single vision with the two eyes is not a simple sensation, but the result of experience, or of judgment, from facts presented to the visual and muscular senses.

Such being the conditions as to the position of the two eyeballs, necessary to single vision, various theories have been advanced, to account for the actual *combination by the mind*, of the two images. By some, this is thought to be dependent on a fixed structural condition, such as a peculiar arrangement of the fibres of the optic nerves, which decussate at the optic commissure, and are supposed thus to bring certain parts of the two retinæ into identical or corresponding relations, as regards the sensorium. The right halves of the two retinæ are supposed to be connected, by the fibres of the two optic nerves, with the right optic sensorial nervous centres, and the left halves of the retinæ, in like manner, with the left optic centres, this arrangement being effected by a supposed semi-decussation of the fibres of each optic nerve. If such an arrangement existed, each optic sensorial centre would obviously receive impressions belonging only to the same side of the field of vision. It is probable, however, that the decussation of the fibres of the optic nerves is not thus partial, but almost, if not quite, complete; for amaurosis of one eye, or section, in animals, of one optic nerve, is followed by withering of the opposite optic tract only. Moreover, in any case, the sensorial impressions, being received by separate bilateral optic nervous centres, are, of course, themselves bilateral or double, and the necessity of explaining their subsequent combination by the mind, still remains.

The actual combination of the two impressions, like the combination of those of hearing, smell, and taste, must, however, be the result of some mental operation, either intuitive, experimental, or rational. There is no doubt that the convergence of the two eyes to a fixed point in the object, is a necessary condition of seeing it single; and of this convergence, the mind certainly acquires, by experience, distinct cognizance, and hence refers both images to one object, as only one object can occupy the same point in space. In certain cases, as in squinting suddenly produced, double vision for a time occurs, but afterwards the mind neglects one or other image; so, too, of the images of the same objects, which fall on non-corresponding points of the retinæ, one is either neglected, or becomes obscured by the stronger impression in the other eye. Doubtless, also, we are constantly neglecting double images formed, in the two eyes, of objects around the point of single vision.

It was shown by Müller, that when the eyes are fixed on a certain point, it is only those objects lying on a curved line, the chord of which is formed by the distance between the two eyes, or rather between the points of decussation of the luminous rays in the two eyes, which appear single. This curved line is named the *horopter* (Aguilonius), and its size and curvature are determined by three points, viz., the centres of the two eyes, and the points towards which the axes of these converge. By Helmholz, however, the horopter is shown to be usually a line of double curvature, formed by the meeting of two hyperbolic, or sometimes of two plane curves. Moreover, when the point of convergence of the eyes is in the median plane of the head, and at an infinite distance, then the horopter is really a plane, parallel to the two visual lines, and corresponds with the ground on which we stand. In near vision, objects exactly in the horopter, are better seen stereoscopically, than those out of it, as may be illustrated by looking at a wire slightly bent, in its middle, towards the eyes, and held in front of the face, first out of, and then in, the line of the horopter, when it will be found that the bend in the wire, is most easily seen in the latter position. So, also, in distant vision, the surface of the landscape, and the distance of its several points, are better estimated, because they lie in the plane of the horopter; for, if the head be turned aside, or inverted, our perception of those distances is less accurate.

In viewing an object situated beyond a certain distance, the convergence of the visual axes is no longer necessary, and it has been calculated that these remain parallel for all objects, the distance of which exceeds 120 feet. The angle formed by the lines of vision of the two eyes at the object, is called the *binocular parallax* of the object; for objects at a distance of 12 feet, this angle measures about 1°; it is, of course, regulated, for each individual, by the interocular distance.

The objects which we have to examine in external nature, are bodies having three dimensions, viz., length, breadth, and depth; in other words, they occupy *space*, and possess *solidity*, however varied their shape, whether cubical, oblong, cylindrical, ovoid, or spherical, whether convex or concave, regular or irregular. In estimating the forms of such bodies with the aid of *one* eye only, we are guided by the ascertained correspondence of certain effects of light and shade with certain constant impressions derived from touch. Experience alone enables us to form complex notions, or judgments, of this kind.

These correspondences are very liable to delusion, or misinterpretation; thus, if we look with one eye, at a raised cameo, or medal, illuminated from the right-hand side, we perceive that its surface is in relief; but, if by an effort of imagination, we suppose the light to come from the left-hand side, the design appears to be in *intaglio*, or hollow. The same effect may be produced by looking at the medal, through a convex lens held at a distance from the single eye, so that the image is reversed, the light still remaining on the right-hand side. These experiments show how completely the ultimate notions derived from our sense of sight are mental.

But, in actual vision, we employ *both* eyes, each of which receives its own image of any given *solid* object. When such objects are within the range of the binocular parallax, the optic axes converge, and, moreover, the images or figures, formed in the two eyes, do not exactly agree; for each eye sees a different aspect of the same solid body, as, for example, of a sphere, a cube, or a book; the right eye seeing more of the right side, and the left, more of the left side, of the object. The difference between the two images, is regulated by the distance of the object, and by the interocular distance. We frequently, indeed, view an object, first with one eye, and then with the other, in order to gain a better knowledge of its form, or its position in space. By a mental combination of these two different perspective impressions, the idea of the solidity of the object is produced, not, however, as a simple sensation, or even as an intuition, but, in the very earliest period of our lives, as the result of a joint action of sight and touch, leading to the formation of a notion of solidity, as producing certain visual appearances of form, light, and shade. Such notions may seem to be intuitive in after life, and have been named *secondary intuitions*.

A good illustration of the effect of the two eyes in giving the notion of solidity, is furnished by the philosophical apparatus known as the *stereoscope*. By the combination, through optical means, of two drawings of a solid object, taken at different points of view, and showing, therefore, two different aspects of the same, this instrument communicates to the mind, the appearance of a *solid* body, or of a body of three dimensions. The *reflecting* stereoscope invented by Wheatstone, consists of two mirrors, placed with their backs towards each other, at an angle of 90°; by means of two sliding frames, one at each side, two different perspective drawings of the same solid object, can be fixed and adjusted, so that their images in the mirrors, are separately seen by the two eyes, placed in front of the converging mirrors. The images thus formed in the two eyes, which resemble the natural images of the object, when this is regarded directly by them, are then mentally combined, as in the case of such natural images, into a single perception. But this only happens, when the eyes receive the images on the corresponding or identical parts of the two retinæ; for if either image is out of place, the two do not coalesce, but are seen separately, and *flat*, not solid. The *refracting* stereoscope, invented by Sir David Brewster, consists of two eccentric double convex lenses, each connected with a sliding tube, by which they can be adjusted to suit the sight and the distance between the two eyes of the individual. Proper perspective outlines of bodies, when viewed through this stereoscope, convey to the mind the idea of solidity. The action of the mind in producing these results, is shown by the fact, that two pictures of similar objects, differing slightly in size from each other, convey to it the idea of an object intermediate in size. Such a combination probably often occurs in ordinary vision; for many retinal images of the same object, must be of unequal size in the two eyes, as, for example, those of near objects placed at different distances, and in different directions, as regards each eye; so likewise, in the case of persons, in whom the two eyes have different focal distances, the two images of a given object must be of different dimensions. But objects at a great distance, those lying opposite the middle of the eye, and those at equal distances from the median plane of the visual field, produce images of equal size. When totally different pictures are viewed in the stereoscope, as for example, a man and a horse, the impressions produced are various; sometimes the two pictures are blended and confused, sometimes they are seen alternately, and sometimes one is neglected, and the other only seen. The brighter picture usually predominates. In the *stereomonoscope* of Claudet, the separate images of a solid object, are combined, by means of two lenses, on the same part of a screen of ground glass, when, by their coalescence, they produce, in the eye of the observer, the stereoscopic effect.

Wheatstone has contrived another instrument, named the *pseudoscope*, which, by diminishing, or increasing, the angles at which the rays of light from an object ordinarily enter the eye, reverses the visual relations between the near and distant points of an image. A concave body appears convex, a convex body, concave; a bust seen from the front, presents the appearance of a deep hollow mask, whilst the interior of a mask looks like a prominent cast. These phenomena are known as *conversions of relief;* they also prove the influence of the mind, in the ultimate interpretation of visual effects.

When we view distant objects, beyond the range of the binocular parallax, the appearances of solidity and relief, and our conclusions concerning these, are arrived at indirectly, or by processes of judgment and experience, in the same manner as when one eye alone is used. Persons who have lost one eye in infancy, must acquire their notions of the solidity of objects, by the conjoined use of touch and sight, aided by movements of the head or body.

The retina conveys to us a distinct sense of *locality*, dependent on the stimulation of two or more points of its surface; and these impressions, projected outwards in the field of vision, furnish us with the means of recognizing *intervals* of *space*. The two first dimensions of space, viz., length and breadth, like those of a solid body, are easily recognized, even by *one* eye, according to the angles formed by the different lines of visual direction; but the third dimension of space, viz., that of depth, is more difficult of appreciation, and requires the use of *both* eyes.

Our estimation of the linear *direction* of external objects, and of their relative, or angular, distances from each other, upwards, downwards, sideways, or obliquely, *i. e.*, of their apparent *position*, can be formed by one eye alone; but for the appreciation of their real position, it is necessary to be able to judge of their *distance* behind one another, or their depth in space. In the case of near objects, we, to a certain degree, estimate their depth in space, in the same manner as we judge of their solidity, by means of a stereoscopic action of both eyes. In this way, we become conscious of the intervention of a certain depth of space between near objects; but in order to estimate more accurately, their relative distance behind each other, it is supposed that we are able, by looking from one object to another, to obtain important data from the muscular movements by which the two eyes are made to converge, and probably also from the changes which ensue in their focal adjustment; this is especially the case in regard to near objects, in looking at which, these actions require a greater effort. The knowledge thus obtained is not a mere sensation, but a mental notion, founded on the judgment, and helped by experience. Infants are entirely unable to judge of distances.

In estimating the real positions of distant objects, beyond the range of the binocular parallax, however, there is no convergence of the eyes, and frequently no focal adjustment is required; here, we are guided by movements of the head, by the effects of different distances on the apparent size of objects, such as are explained by linear and plane perspective; by the changes in the distinctness of outline, shadow, detail, and color, due to aerial perspective; by the manner in which objects intercept, or are intercepted by each other; by comparison with known objects, and, if these are in motion, by their absolute and relative rates of movement. It is by the perception of objects in space, that we obtain, through the eye, as well as through touch, materials for the mental conception of space itself.

An inexact estimate of relative distances, leads to certain errors as regards the sizes of objects. Thus, the idea that the sky at the horizon, is more distant than the sky directly above us, an idea dependent on the number of known and near objects between us and the horizon, leads to an erroneous estimate of the size of the rising or setting sun or moon, which thus appear to us larger than when they are seen above our heads. According to another view, the image of the sun or moon, seen near the horizon, is compared, by the mind, with the smaller images of intervening distant objects known to be of great size, and so those luminaries are interpreted to be of larger dimensions than when seen in the open sky. Through a telescope, these bodies appear nearer than they are, and hence the magnifying effect is underrated by the observer. Convergence of the eyes, also influences our judgment of distance; for, and this is remarkable, a fixed object appears smaller, when the optic axes are made to converge in front of it. In railway travelling, objects passed near the side of the road, appear larger and nearer, than they are, because their rapid movement past each other, suggests, as we shall see, large *angular motion*, and therefore unreal proximity. Objects seen through a fog, seem larger than they are, because their indistinctness suggests the notion of great distance.

We are only able directly to perceive the *movements* of objects, when these take place in a direction *across* the field of vision, in which case, the image of the moving object has a motion across the retina, and hence the motion is perceptible. Movements in the direction of the line of vision, *i. e.*, from, or towards, the centre of the eye, are not immediately perceived, the image, as a whole, having no motion across the retina, although its dimensions undergo increase or diminution, according as it is approaching or receding. The *apparent movement* of an object, from one point in the field of vision to another, depends either on the motion of the image upon the retina, or on the motion of the latter in regard to the image. The extent of this motion, is measured by the angle formed in the eye, by two lines drawn through the eyeball, the one from the point whence the object moves, the other from the point where it is arrested; hence the movement is termed the *angular motion* of the object. This motion may be too slow to be easily observed; and, on the other hand, unless the perception of a moving body be sufficiently prolonged in time, it appears to stand still; as when a rapidly moving body is instantaneously illuminated by an electric flash; or as when the capillary circulation in the web of the frog's foot, is momentarily looked at under the microscope.

We judge of the *real motion* of objects from point to point in space, when these are within the range of the binocular parallax, by a stereoscopic use of both eyes; in estimating the actual direction and extent of the motion, we are assisted by those changes in the convergence and adjustment of the eyes, which are essential to keep the moving object in sight. Moreover, changes in size, distinctness of outline, and color, and the passage of the moving body before or behind others, assist us in the formation of a judgment. In the case of objects beyond the range of the binocular parallax, these latter are the only data on which we base our conclusions.

It has been remarked, that when a given object approaches, or recedes from, us, the estimate formed by the mind of its real size, does not become confused or altered. It must, however, be added, that this is only true of objects moving at a moderate rate; for certainly, as any one may find by experience, a locomotive engine, advancing rapidly towards the eye, on a straight piece of railroad, appears to swell out, or, as it were, to *grow*. The movement is here too rapid for the eye or mind not to be deceived. The explanation offered of the accuracy of our perceptions under ordinary circumstances, is, that, whilst the increase of size in the retinal image of an approaching object, suggests an increase in its dimensions, yet the convergence of the two eyes necessary for the distinct vision of the object, is accompanied by a reduction of its apparent magnitude. The two effects, therefore, counteract each other. In the case of a receding object, the opposite conditions occur.

The movements of the eye itself, are accompanied by movements of the retina, as it were, *behind*, or *through*, the images of the various objects in the visual field; if the eyeballs be rapidly moved, these objects appear to acquire a general motion. There is, however, no apparent motion of the objects in regard to each other, for the relative position of their images remains unaltered. When we are carried through space in one direction, as in railway travelling, objects appear to move in the opposite direction, and near objects appear to pass us relatively faster than more distant ones, for the angular motion of objects is greater, the closer their proximity to the eye. This assists us in judging of the rapidity and uniformity of our own movement, as well as of the distance of objects. If we look intently at certain objects in motion, after a time they seem to be at rest, and ourselves appear to be in motion; thus, on watching a running stream from a bridge over it, the stream soon appears to be still, whilst we seem to be moving with the bridge, in the opposite direction.

Such being the modes in which sight is employed for the purpose of informing us of the presence, size, shape, position, and movements of external objects, there yet remain many phenomena of vision which require to be considered.

For the stimulus of light to produce an impression upon the retina, it is essential that the portion of its surface acted upon by the luminous rays, be of a certain size, that these rays be of a certain strength, and that the retina be exposed to their action for a certain period of time. Images of luminous objects of a certain magnitude, might be regarded as mosaic patterns, composed of an infinite number of minute luminous points; theoretically, these are infinitely smaller than the ends of the retinal rods. It has been calculated that a body, the image of which occupies only $\frac{1}{34500}$th of an inch of the retina, is visible to the eye, which is considerably less than the diameter of a single retinal rod or cone. It is said, however, that two impressions are distinctly or separately perceived, only when a certain distance intervenes between them; this is said to correspond with the diameter of the cones. White bodies on a black surface, or black bodies on a white surface, which measure as little as $\frac{1}{400}$th of an inch in diameter, can be seen by the naked eye; bodies still smaller can be perceived, if the attention be fixed, and the light powerful, though their outline becomes indistinct; but if less than $\frac{1}{540}$th of an inch in diameter, they are no longer visible, although they can still be seen when arranged in rows. Lines, such as opaque threads, are visible, even when only $\frac{1}{4900}$th of an inch in thickness. Bright bodies of exceedingly small size are visible, which, were they less brilliant, would be invisible. If the light be not of a certain intensity, the retina is not aroused to vision; the appearance of darkness in this case, is dependent, not on a total absence of light, for it is still present, but on its want of intensity. When an opaque body passes before the eyes with great velocity, the period of time during which it is visible, is so brief, that the retina receives no impression of the object; hence cannon-balls are invisible when they pass before us, but not always when they approach or recede from us. Luminous bodies, on the other hand, however rapid their course, and whatever their direction, are always visible.

Luminous rays from a small object, falling on the retina, not only excite impressions in that portion of the retina which receives them, but also in the surrounding surface for a certain distance. The stimulation of the retina by the luminous rays, is, it would seem, diffused over the portions of the membrane contiguous to that directly exposed to the action of the stimulus. This diffusion of luminous impressions is known as *irradiation.* The phenomenon is particularly observed in looking at bright objects on a darker ground. It is owing to irradiation, that minute white objects painted on a black ground, not only appear much larger, but are visible at greater distances than natural; whilst, on the other hand, dark objects of the same size on a white ground, appear smaller, and sooner become invisible at a distance. A narrow bright strip of paper seems wider than a dark one of equal size. The larger apparent size of the stars, as the sky becomes darker, and the peculiar appearance noticed in the new moon, viz., that its light crescent seems to belong to a larger sphere than the feebly illuminated portion of its surface, are also due to irradiation. In certain cases, the increased size, or blurred image, of a luminous object, is owing to defective accommodation of the eye, and to dissipation of the luminous rays.

Impressions made upon the retina have a certain *duration.* They continue to be perceived during a much longer interval than the impressions which produced them, and their persistence is greater, the greater the persistence of the original impressions. They are of the nature of after-sensations, or the so-called *spectra*, and have been named the *primary* or *positive after-images.* They last generally about $\frac{1}{50}$th of a second, but may endure for $\frac{1}{2}$ a second. Their average duration is about $\frac{1}{8}$th of a second (Plateau). Were it not for the duration of impressions, vision would not be continuous, for in every act of winking, all surrounding objects would be lost sight of. Impressions, occurring at shorter intervals of time than those just mentioned, are not perceived as distinct or separate. It is owing to the duration of the sensation, that after looking at a vivid light or a bright color, if the eyes be closed, or the head be suddenly turned away, the impression continues for a certain period. The effects of different colors presented, in rapid succession, to the eye, as illustrated in experiments with the *color-top,* which is a spinning-top painted in differently-colored segments, also depend on the duration of retinal impressions. Various secondary or tertiary colors, and even a tolerably pure white, are produced by the rapid rotation of differently-colored tops. The appearance of a complete circle of light, which is seen on rapidly whirling round a stick lighted at one end, the curved lines of fire seen in a lighted "Catharine wheel," and the indistinct haze caused by the rapid revolutions of the spokes or other parts of a wheel, are explained in the same manner. If a small piece of cardboard, on one side of which there is painted a bird, and on the other a cage, be made to revolve rapidly by twisting strings fixed to each end, the bird appears to be in the cage. The toy known as a *thaumatrope* or *stroboscope*, consists of a disc, on which are painted sets of figures of men or animals, in the different positions of some act, as, of leaping, running, or tossing balls; when it is made to revolve, and the figures are looked at through a slit, they are combined into one image, which appears to be in motion. When two exactly similar toothed wheels, placed one in front of the other, are made to revolve, in the same direction, and at the same rate, the image appears stationary; but if the number of teeth, or the rate of velocity, differs in the two wheels, then a revolving image is seen (Faraday). After looking for any length of time, at objects in motion, the appearance of movement may be communicated even to stationary objects; thus, after having been on the sea, all surrounding objects appear, for a time, as if they were in a state of constant upward and downward movement.

When the retina has been previously in a state of repose, especially in cases of prolonged residence in the dark, the influence of any given quantity of light, as well as the rapidity of its action, and the duration of its impressions on the eye, are much greater than when it has previously been in a state of activity. If the intensity of the light be very great, the painful effect called *dazzling*, is produced, and the nervous power of the retina may be permanently destroyed, as, for example, when a flash of lightning suddenly annihilates vision. On the other hand, blindness may result from the continuance of the opposite condition; for if the eye be deprived of sufficient light, for a very lengthened period, blindness will ensue from want of exercise of the retina. If the eye, previously in a state of rest, be suddenly exposed to a bright light, the rays impinging upon the retina through the dilated pupil, are painful to the eye, and vision is confused, till the pupil, having had time to contract, a large number of the rays are excluded, and the retina itself, moreover, becomes accustomed to the excess of light. When a sudden transition takes place from light to darkness, opposite changes of course ensue.

The relative intensity of light is measurable by means of instruments called *photometers*, the action of which is, however, entirely dependent on the discriminating power of the eye itself, through the comparison of shadows of different strengths. We have no means of estimating the absolute quantity or intensity of light. It is possible to read with both eyes, during twilight, when the employment of one eye would be useless; and, moreover, a brilliant light dazzles, or blinds, the two eyes, more rapidly than it does one. At the same time, no difference of brightness is ordinarily observable, whether we look with one eye or with both; for on closing one eye, the pupil of that eye dilates, and, consentaneously, that of the other, so that more light is admitted to the open eye.

There are many interesting points connected with the so-called *secondary*, or *negative*, *ocular spectra*, which are distinguished from the primary or positive spectra, by not resembling the original impression. If, after looking at dark, white, or luminous objects, the eyes be covered, so as altogether to exclude the entry of light, images of these objects, or impressions related to such images, the results of *after-sensations*, remain upon the retina, and these are named negative spectra. In the case just mentioned, of closing the eye, the spectra are dark, white, or luminous, like the original causes of the visual impressions. But if the eyes, after looking steadily at a white object or spot, on a dark ground, instead of being closed, be turned towards a white surface, the spectrum perceived is black. If the condition of things be reversed, the spot being black, and the ground white, the after-image left is white. This difference in the appearance of the spectrum, as compared with the object, is thus explained. In the first experiment, the portion of the retina on which the image of the white spot has been received, being exhausted, is less susceptible of the action of a given quantity of light, than the surrounding unexhausted portion which corresponded to the black ground, and, therefore, though receiving white light, it is less acted on by it than the rest of the retina. On the other hand, in the second experiment, the portion of the retina which has received the image of the black spot, is unexhausted, and is therefore more susceptible than the rest, of the action of a given quantity of light. For the same reasons, the spectrum, produced by gazing at the sun, and then turning the eyes from it, is dark, if the eyes be turned towards a white surface, though it is luminous, if the eyes be closed, or directed towards a dark surface. The spectra, which result from the impressions of colorless objects, are, as a rule, themselves colorless. But when luminous rays of great intensity fall upon the retina, different phenomena ensue. Thus if the eyes be turned towards the sun when shining brightly, and then be covered, the spectrum, at first, is of the same color as the sun itself, but rapidly assumes different colors in regular succession, before it vanishes; it first becomes yellow, then orange, red, green, violet, and black. When the eyes, instead of being covered, are turned towards a white surface, the after-image passes through the same series of colors, the order, however, being reversed. In any case, these colors are due to certain states of the retina, and are called *subjective*, *accidental*, or *physiological colors*. The spectra thus formed, move with the eyes; their size increases with the distance of the surface on which they are projected; their vividness and duration are proportional to the strength and duration of the primary impression; and they fade away gradually, with successive changes of color. These after-images are weaker in the sides of the eyes, than in the centres or points of distinct vision; they may be produced by objects to which the attention has not been directed; and there are persons who have a singular power of retaining or reviving them.

The most remarkable spectra are those produced by the impressions of distinctly colored objects. The color of the spectrum, in these cases, is always complementary to that of the object; thus, if after looking steadily at a red object, the eye be turned on to a sheet of white paper, the spectrum is green; the spectrum of a green object, in the same manner, is red; that of a blue object is orange. The explanation of this, is, that the retina is so exhausted as regards the color first looked at, that it is no longer so readily excited by the corresponding colored rays of the white light, which pass from the surface of the paper, but only by the complementary rays. After looking at a given color, and then turning the eye to the complementary color, the latter appears brighter and more intense than natural. Primary colors are more exciting to the retina than secondary and tertiary colors; and of the three primary colors, red is the most exciting, and blue the least so. Contrasted colors, and contrasts of light and shade, heighten their separate effects. Thus, the depth of shadows is always greater, in proportion to the intensity of the light which produces them. Gray spots occupying a white surface, present a darker appearance than a gray ground of the same tint. The production of the physiological colors by contrast, as just mentioned, is a further example of this class of phenomena. A strip of gray paper placed on a bright colored field, presents a faint tint of the color which is the opposite of that of the surface on which it lies; on a red surface, it frequently has a greenish tint; on a green surface, a reddish tint, and so on. Such phenomena are only produced, when the surface of the field is of a very bright color, and when the portion of the retina exposed to the action of the new color, is in a state of relative repose (Müller).

When, by means of the stereoscope, two different colors are thrown upon corresponding points of the retina, the impressions sometimes alternate; sometimes one color preponderates: at other times one color appears in one part of the visual field, and the other in the other part; and, lastly, the two colors may be blended into a mixed or compound color. These curious experiments prove that the impressions are more or less blended in the sensorium. The blended colors are usually very bright. On looking with one eye through a colored glass at the sky, and keeping the other eye closed, or looking with it at the sky without a glass, it is found that in the former eye, there arise spectra of the *complementary* color to that of the glass, in the latter, spectra of the *same* color as that of the colored glass. The former eye is sufficiently excited to produce secondary or negative spectra, whilst the latter, less perfectly stimulated, but still affected through the color in the other eye, only produces positive spectra.

Irritation or congestion of the retina, altered conditions of the optic sensorium, diseases of the brain, dreams, and peculiar mental states, give rise to various kinds of spectral phenomena. Bodies seated in, or on, the eye, also produce appearances in the field of vision, called *entoptical* images, such as *motes*, or *muscæ*. Thus, fixed particles of blood, lymph, or pigment, on the retina, or others in the lens, such as radiated streaks or spots, cause *fixed muscæ;* and movable particles, on the surface of the cornea, such as tears or mucus, in the aqueous humor, or in a softened vitreous humor, cause *muscæ volitantes*, or *flying muscæ.* They are of various forms, some looking like spots or streaks, others assuming a hair- or bead-like shape.

Such of these entoptical images as are caused by objects in front of the retina, are named *extra-retinal.* They are not usually noticed, because light passes behind the little objects, which would otherwise cast a shadow on the retina; but by admitting the light into the eye, through a minute hole in the card, so that the retina receives rays from one direction only, distinct shadows of such objects are cast on the retina, and produce the entoptical images. If the orifice in the card be in the principal anterior focus of the eye, that is, about half an inch in front of it, the entering luminous rays become parallel behind the lens, and the images are of the same size as the object; if the card is nearer the eye, the rays diverge, and the shadows are larger; if it is moved further off, the rays converge, and the images are smaller. The *intra-retinal* images include those of the bloodvessels, and the blood moving in them, described by Purkinje, who showed, by means of a simple experiment, that most persons are able to see the shadows of their retinal bloodvessels. The vascular image of the retina, or the *image of Purkinje*, is best perceived, by moving a lighted candle up and down, or in a circle, a few inches in front, and to one side, of the eye, so that the light may enter it obliquely, this being done in a dark room, or when the eye is directed towards a dark surface. The appearance of a bright field, moving with, and before, the eye, is then gradually excited; on it are seen dark arborescent vessels, branches of the central artery and vein of the retina, and even images of the optic eminence and yellow spot. The rods and cones of the retina are excited by the luminous rays, its general surface being thus illuminated; but the parts of its bacillary layer, which are covered by the vessels, being relatively more protected from the light, are perceived as dark arborescent ramifications, always much larger than the vessels themselves, since they are projected into the visual field. In accordance with the principles of visual direction, the appearances are, moreover, reversed, the optic eminence of the right eye being seen on the outer side of the yellow spot. The shadows of the vessels shift considerably, when the candle is moved about; and, as these vessels lie chiefly behind the nerve-fibres, but in front of the rods and cones, it would certainly appear that the last-named parts are the recipient portions of the retinal structures. Another, and more striking, experiment consists in looking steadily at a uniform field of light, such as the sky, or an illuminated ground lamp-glass, and rapidly moving the finger, to and fro, in front of the eye. After a time, delicate reddish images of the retinal capillaries, and even of the blood corpuscles moving in them, are seen on the luminous field. This form of intra-retinal image has been made use of, to determine the velocity of the blood in the capillary vessels: it appears to be from $\frac{2}{100}$th to $\frac{3}{100}$th of an inch per second (Vierordt). Pressure will also produce entoptical images of the retinal vessels, and also of those of the choroid, shining on a silvery blue ground.

The dark field observed when the eyes are closed, or kept open in a perfectly dark room, is not absolutely black; it is often, from retinal excitement, covered with an obscure luminosity, and sometimes with minute points of light, like *luminous dust.* This field is not circular, but elliptical, like the ordinary visual field; it is projected into the exterior, moves with the eyes, and is itself the result of a positive sensation, quite distinct from blindness. The size of this dark field diminishes in the horizontal direction, when the closed eyes are made to converge.

The curious spectra, named *phosphènes*, caused by pressure, with the finger, on the closed eye, have been previously mentioned, as well as the fact, that these luminous impressions are always referred to a direction opposite to that of the seat of pressure; pressure on the inner side of the eyeball, for example, excites a luminous spectrum which appears on the outer side. It was noticed by Müller, that pressure, with the finger, upon the eye, gives rise to a variety of luminous impressions, these being either annular, star-like, or square. But, according to Serre, the shape of these phosphènes is determined by that of the body which exercises the pressure, and by the extent to which the retina is acted upon by it. When the pressure is communicated by the finger, the spot is either roundish, or when the pressure is strong and widely spread, it is annular, forming a ring with a dark centre. When the pressure is made by a circular, triangular, or square object, the luminous figure is circular, triangular, or square, provided that the part compressed is entirely over the retina. But if the pressure be applied over the anterior margin of the retina, it gives rise to an incomplete figure, which becomes more so, the smaller the portion of the retina covered by the compressing body. A second spectrum is often perceived, in a direction corresponding with the point of pressure. This is produced by a change in the form of the coats of the eyeball, on the side opposite to the seat of the primary pressure; it is always a complete figure, because the retina itself is there continuous; such counter pressure acts on some portion of the deeper part of the eyeball. Lines connecting the primary and secondary phosphènes, or the points of the retinal surface by the stimulation of which these are produced, traverse a common centre of direction, which lies in the middle of the crystalline lens, and may be said to correspond with the visual centre of direction.

Light is the proper homologous stimulus of the retina, but various other, or heterologous stimuli, such as irritation, blows, or pressure on the eyeball, or electrical shocks, excite luminous, and even colored sensations or spectra of various kinds. Even the action of the orbicular muscles of the eyelids, or the sudden movement of the eyes from side to side, will excite luminous impressions. Visual sensations, like all other sensations, may also be excited by internal stimuli. Thus, when the eyes are closed, and the retina is at rest, the field of vision is dark; but, if the optic nerve, or sensorial centre, is in a state of excitement, impressions of luminous rays, or of bright colors, are perceived. During congestion of the brain, each arterial pulse is accompanied by an alteration in the degree of light perceived by the eyes, owing to a pulsating illumination of the field of vision (Müller). Certain chemical agents, when absorbed into the circulation, also give rise to the sensation of light, either by producing some alteration in the condition of the retina, the effects of which are transmitted, through the fibres of the optic nerves, to the brain, or perhaps by affecting the nerve, or the sensorial centre itself. The action of opium, digitalis, and belladonna, in producing spectra, is well known, and the vivid and horrible spectral illusions seen in fever, and especially in delirium tremens, have often been described. Again, the motion of the blood is sometimes observed, especially after gazing at bright surfaces, such as the sky, or after looking for a certain time at a white surface. Indistinct movements in the luminous visual field, are then noticed. The appearance of dark bodies in rapid and constant motion, seen in cases of congestion of the brain, and also on suddenly rising from a stooping posture, are dependent on the movement of the blood, exciting luminous impressions. As elsewhere stated, no instance of the occurrence of these or other true spectra, where the two eyeballs have been removed, appears to have been recorded; so that it has not been proved that such spectra can occur without the intervention of the retinal elements. Cases of disease of the retina, involving total blindness, are not quite satisfactory as evidence of this, for the retina may still be exceptionally excitable.

In many persons, the sensibility of the retina to colors is remarkably acute, enabling them to discriminate between shades of the same color, which, to other persons, present no difference. There are others whose sensibility to certain impressions of color, is curiously defective. This affection, known as *achromatopsy*, *color-blindness*, or *Daltonism*, consists in an inability to distinguish one color from another. It is more common in the male than in the female, and is often hereditary. In some cases, it is limited to the lighter tertiary tints, which cannot be distinctly recognized; or there may be inability to distinguish some of the secondary colors; or the insensibility of the eye to colors may be so great, that one of the primary colors, usually red, may not be recognized, constituting *dichromism* (Herschel). Thus, bright red is, by some persons, indistinguishable from green; ripe fruit, such as cherries, being, to them, of the same color as the leaves. Lastly, some individuals can only distinguish black, white, and gray.

Insensibility of the eye to colors is sometimes a temporary affection dependent on internal causes, such as congestion of the brain, retina, or choroid, or it may be due to a deranged condition of the digestive organs. As to the cause of color-blindness in general, nothing is known; it probably has its seat in the retina, perhaps in some deficiency in the structure or energy of the rods or cones; just as defects in the appreciatiom of pitch and timbre, in the hearing of certain individuals, are supposed to depend on defects in the rods of Corti, or of some of the other complex structures of the cochlea. By some, however, the cause of this defect is believed to be in the sensorial nervous centre; it has also been suggested, that it may be due to a peculiarity in the absorptive property of some of the humors of the eye. Comparatively harmless in most persons, this defect may be of serious consequence in the case of railway guards, pointsmen, or sailors, who have to watch signals given by means of colored lights.

It is by the forms and colors of the retinal images, that we judge visually of the forms and colors of the material world; but the sense of sight is educated by experience, and by comparison with the results of the tactile sense, and thus, as we have seen, suggests to us complex notions. This fact is illustrated by the cases of persons born blind, who are said at first to imagine that the field of vision is flat, and even that objects touch the eyes. The education of the eye, for distant vision in sailors, for the detection of minute objects by the microscopist, and for the appreciation of form, texture, and color, in various commercial and manufacturing pursuits, as well as amongst artists, is well known. There is often a mental, as well as a visual, training in these persons. An acquired acuteness of vision may become hereditary, as would seem to be the case in the Mongols and Hottentots. The sense of sight is more liable to individual differences, and to illusions than any of the other senses.

Of the luminous rays which pass, through the pupil, on to the retina, a certain number are reflected by the choroid, the retina, and the transparent media of the eye. Some of these reflected rays impinge on the posterior surface of the iris, and are there absorbed by the uvea; this structure also absorbs certain rays, passing from the borders of the lens, which would otherwise confuse and dazzle the retina. Some of the rays reflected from the bottom of the eye, however, pass out through the pupil, and converge to a focus; these are few in number, and do not, when the eye is ordinarily examined, afford information as to the condition of the deeper ocular structures. But light may be thrown into the eye in such quantity that, when reflected from its deep parts, it furnishes us with this information; and an ingenious instrument, named the *ophthalmoscope*, has been invented, by means of which the interior of the eye can be easily seen. It consists of a circular, slightly concave, mirror, having a focus of about ten inches, perforated in the centre by a small aperture, and fixed in a handle. The pupil of the eye to be examined, is previously dilated by the introduction of a few drops of a solution of atropine between the eyelids, and the examination is made in a darkened room. A lamp is placed close to, and on a level with, the eye to be examined, care being taken that none of its rays fall directly on the eye. The observer sits near to, and facing, the eye, and holding the mirror steadily in one hand, brings the rays from the lamp to a focus on the retina; he then takes a convex lens, having a focal length of from two and a half to three inches, in the other hand, and holds it about two and a half inches in front of the cornea. The anterior parts of the eye can be generally examined without the aid of the lens; by its use, however, the optic eminence, the yellow spot with its elevated rim, and the arborescent vessels of the retina, can be distinctly seen, but in an inversed position; the retina, as thus examined, appears to be of a shining red color. In the healthy condition, the crystalline lens is invisible. Various diseased states of this and the deeper structures are, however, easily distinguishable by the aid of this useful instrument.

The Organs and Function of Sight in Animals.

The general structure of the eyeball, and the uses of its several coats and humors, are similar in all the Vertebrata, and correspond with the structure and functions of the same parts in Man. But many modifications in these organs, are observed in the several vertebrate classes. In Mammalia, there are noticed, in the first place, remarkable differences in the size of the eyeballs, which, as a general rule, are larger in proportion to the powers of vision, in any given animal. Some species of nocturnal habits, have very large eyes, as noticed in the lemur, dormouse, aye-aye, &c.

The Carnivora generally, have eyes of moderate size; in the seals, the coats of the eyeball are strengthened, to enable it to resist the pressure experienced during submergence. In the insectivorous Cheiroptera, the eyes are usually small, except in some nocturnal species. In the mole, which lives habitually in darkness, the eyeball is so extremely minute, that even its existence has been denied; it possesses, however, the usual parts, and is supplied by a branch of the fifth cranial nerve ; the optic nerve is said to be absent, although the optic tracts and commissures exist. Amongst the Pachydermata, the eyes are small. In the Cetacea, the thickness of the coats of the eyeball, especially at its hinder part, is enormous, in order to preserve its shape, under the pressure of different and extreme depths of water.

The eyeballs are of great relative size in the Ruminants and the Solipeds ; they are generally far apart, and very prominent. In the camel and giraffe, their position is so lateral and projecting, that those quadrupeds can look backwards, without turning their heads. The usual direction of the antero-posterior axes of the eyeballs in Mammalia, is obliquely forwards and outwards ; but in the Quadrumana, the eyes are directed forwards, as in man ; whilst in the Rodentia, the direction of the axes of the two eyes, is completely lateral.

In such cases, the relation between the parts of the retina, must be peculiar. The images of objects, seen in *front* of the animal, must fall, not as in man, on the outer half of one retina, and on the inner half of the other, but on the outer halves of both retinæ, and on identical points of the two retinæ, occupying inverse positions as regards the axes of the eyes. Objects placed directly to either *side*, must be seen independently in the corresponding eye, and the points of the retinæ on which they are received, can have no correspondence or identity with each other ; otherwise, two similar objects, seen, one on the right, and the other on the left hand, would be combined, and appear as one object. It is not yet known whether the decussation of the optic nerves, presents peculiarities, in accordance with the special seats of the identical points of the retinæ in these animals, and with the absence of identity in other parts of the retinæ.

In certain Mammalia, the orbital fascia or membrane, which completes the orbit, contains plain muscular fibres, and when the sympathetic nerve is irritated, it contracts, and presses the eyeball forwards. In the Mammalia generally, the third eyelid, or membrana nictitans, is well developed ; in the elephant, it is provided with two special muscles, and has a very strong fibro-cartilage embedded in it. In the Ruminants, the third eyelid is provided with a large gland, named the *Harderian* gland, the mucous secretion of which facilitates the motion of that membrane over the eyeball. In the Sirenia, amongst Cetacea, the eyelids are represented only by a border of loose skin, the margins of which are provided with small mucous glands ; a membrana nictitans is present ; in the Cetacea proper, this is the only structure which supplies the place of the eyelids. No lachrymal gland exists in the Cetacea. This gland, however, is very large and lobulated in all the Ruminantia. In the deer, and in some antelopes, the so-called *tear-pits*, formed by recesses in the lachrymal bones, between the orbit and nose, are met with ; they are lined by an extension of the integuments, and open externally by a gutter-like aperture.

The muscles of the eyeball in almost all Mammalia, resemble those of man ; but, except in the Quadrumana, there generally exists a seventh ocular muscle called the *retractor oculi*, or *choanoid muscle*, interposed between the recti muscles and the optic nerve. In seals, the crystalline lens is more nearly spherical than in other Mammalia, in accordance with the requirements for the production of distinct images under water, as will be mentioned in speaking of the eyes of fishes. In the castor-beaver, the cornea is likewise flattened, and the lens nearly globular, to suit its aquatic habits. The vitreous humor in the Cetacea, is much flattened from before backwards ; the cornea is also flat, but the crystalline lens is, as in seals, nearly spherical. In the Ornithorhynchus, a cartilaginous plate, projecting from the orbit, protects the eye above ; the sclerotic coat is also cartilaginous, the cornea is flat, and the lens small.

In many Mammalia, the bottom of the eyeball is partially lined by a membrane, called the *tapetum*, which presents different brilliant hues ; it consists of a layer of thin fibres, or, as in Carnivora, of nucleated cells, of metallic brilliancy ; this reflects the rays of light from the bottom of the eye, like a concave mirror, and causes a luminous appearance in the eyes of those animals in the dark. In Ruminants, Solipeds, and Pachyderms, the tapetum presents a greenish-blue metallic lustre; in most Carnivora, it has a silvery hue, excepting in the cat, in which it is green; sometimes it resembles mother-of-pearl. The Quadrumana, Edentata, and Monotremata, like man, have no tapetum. The shape of the pupil also presents peculiarities in certain Mammalia; thus, in the cat it is elliptical, and even linear, in a perpendicular direction, when contracted under a strong light. Solipeds and Ruminants have a transversely oblong pupil. It is remarkable that the yellow retinal spot is, as a rule, absent in Mammalia, the only exceptions being in the Quadrumana.

In Birds, the eyelids are well developed, and, except in owls and a few others, the lower lid is generally more movable than the upper one; contrary to what occurs in Mammalia, it covers the larger part of the eyeball, and is even provided with a special depressor muscle. The third eyelid, or membrana nictitans, is always present, and fully developed; in birds of prey, it is in constant use, serving to cleanse the eyeball, or to temporarily diminish the glare of bright sunlight; it is sometimes nearly transparent, but usually rather opaque. The nictitating membrane folds back on the side next the nose, by the action of its elastic tissue; but, for its projection over the front of the eyeball, two muscles are provided. Of these, one, named the *pyramidalis*, is a slender muscle, arising from the sclerotic, passing behind the back of the eyeball, curving over the optic nerve, and ending in a tendon, which slides through the border of the other muscle. This muscle, named the *quadratus*, descends from the upper part of the eyeball, and forms a muscular pulley for the tendon of the pyramidalis. After escaping from the pulley, this tendon continues over the back of the eyeball, and finds its way to the lower border of the nictitating membrane. The contraction of the pyramidalis pulls the membrane across the eyeball; whilst the quadratus prevents the tendon of the muscle from straightening itself, and so coming down upon the optic nerve. Birds have, in addition to the ordinary lachrymal gland, a large Harderian gland, situated behind the conjunctiva, at the nasal angle of the eyelids. The muscles of the eyeball are the same as in Mammalia; the superior oblique does not, however, pass through a pulley.

The eyeball of the bird is very large in comparison with the size of the head and brain, especially in the nocturnal birds of prey. It is not usually so spherical as in Mammalia, but is sometimes somewhat flattened, and, in the larger raptorial birds, is often lengthened by the prolongation of the anterior part of the sclerotic, and by the extremely convex form of the cornea. Movable bony plates, situated in the sclerotic, frequently preserve this elongated form, an arrangement also found in certain reptiles and fishes, though in them, the eyeball is flattened. The choroid coat in birds generally, sends forwards into the vitreous humor, from near the entrance of the optic nerve, a remarkable plicated vascular membrane, named the *pecten*, or *marsupium*. This is falciform, or irregularly quadrangular in shape; its plicæ, or folds, are, in some species, only four, but, in others, nearly thirty in number. The pecten sometimes reaches the posterior part of the capsule of the lens. It is not muscular, but is supposed, by means of changes in the state of distension of its vessels, to alter, either directly or indirectly through the vitreous humor, the position of the lens in the interior of the eyeball, and to assist in adjusting the focal distance of the eye. The action of the pecten, which varies in size and shape in different birds, is, however, not well understood. The Apteryx australis is the only bird in which the pecten is absent. The iris is usually very active, and contains striated, as well as unstriped, muscular fibres; its movements are more active and rapid than in other animals, in which it contains only plain muscular fibres; and, in some birds, it is said to be even under the influence of the will; its color varies, but it never exhibits a metallic lustre. The pupil is generally round, though it is lengthened vertically in the owl, and horizontally in the dove and goose. The internal ciliary muscle also exists, and doubtless influences the form and position of the lens; whilst the muscular fibres around the circumference of the cornea (Crampton), and even the proper muscles of the eyeball, may, by compressing its movable osseous plates, alter the relative convexity of the cornea, and so assist in focussing the images of objects upon the retina, however variable their distance. The power of adjusting the eye to accurate vision at different distances, exists in much greater perfection in birds than in any other animals. Vultures, *e. g.*, fly at great altitudes, and yet discern their peculiar food; and other birds of prey, which, in their rapid flight, diminish so suddedly the distance between them and the objects of their pursuit, afford a further illustration of this wonderful power of adjustment. The crystalline lens is flattish, especially in vultures, which are so long-sighted; but it is rounder in owls, which are extremely near-sighted; it also becomes progressively more spherical in aquatic birds, according to their subaqueous habits, being less so in cormorants, more so in ducks, and still more so in divers.

Amongst Reptiles, serpents are destitute of eyelids, the skin being continued over the cornea. In crocodiles, tortoises, and turtles, the two eyelids are well developed, but there are no eyelashes. In the chameleon, the skin forming the eyelids is united into a circular zone with a central aperture. The membrana nictitans and the Harderian gland, when present, are both of large size. The lachrymal apparatus exists in all cases; the lachrymal gland is very large in the turtle. In the Chelonian reptiles, the sclerotic contains a cartilaginous or bony ring. The pupil in the crocodile and many Ophidia, is elongated vertically; it is, however, frequently round, and sometimes of a rhomboidal figure. There is sometimes a rudimentary pecten. In the aquatic species, the cornea is flattened, and the lens of a globular shape; but in the terrestrial species, the lens is flatter; in Emys, it appears elliptical. When the lens is not globular, the cornea is more prominent.

The Amphibia are provided with eyelids, and the membrana nictitans is moved by its own muscles. The lachrymal apparatus is absent. In the frog, there are only three recti muscles; the oblique are absent; but there is a transverse muscle, which passes directly under the eyeball, and is attached to each side of the orbit. The sclerotic is cartilaginous, the choroid well developed, the iris is said to be motionless, the cornea flat, and the lens spheroidal.

In Fishes generally, the integument passes over the eyes, forming a transparent covering; there are neither eyelids nor lachrymal apparatus, the medium in which these animals live maintaining the cornea moist and clean; but in the sunfish, and in a few species of sharks, there are eyelids, and, it is said, in the latter, even a membrana nictitans. The eyes are usually of large size, especially in those fish which live at the bottom of the ocean; they are smallest in those which burrow in the mud. In the Amphioxus, there are two dark spots, on which, according to Vogt, a hemispherical lens is found immediately beneath the integument. The eyeballs of fishes are lodged in very large, cartilaginous, or bony sockets, and are usually provided with four recti and two oblique muscles; they are symmetrically placed on the sides of the head, their usual direction being outwards, but sometimes upwards; in the flat-fishes, owing to the peculiar conformation of the cranium, both eyes are situated on the same aspect of the head. In fishes generally, the eyes are so completely lateral, that the visual field of each must be almost or entirely independent; and it is remarkable that in these animals, there is no optic commissure, the optic nerves being entirely unconnected, and completely decussating, one optic nerve passing over into the opposite optic tract. In the Amphibia, Reptiles, and Birds, the optic nerves, as in the Mammalia, are more or less blended at the optic commissure.

It may here be mentioned, that the decussation of the optic nerves in the Vertebrata, an arrangement which, not having been met with, even in the highest Mollusca or Annulosa, may be typical of the Vertebrate organization, seems to be related to the decussation of the motor tracts in the medulla oblongata, which is likewise quite peculiar to the Vertebrate type of structure, not occurring in the Annulose or Molluscous animals. The constant use and importance of sight, in the government of the movements of animals, probably necessitates a co-ordination between the visual and motor organs on the two sides of the body; but why this cross-action should prevail in Vertebrata, and not in the non-Vertebrata, has not been hitherto explained. A suggestion may here be offered, viz., that it depends upon the inversion of the retinal images within the eyes of the Vertebrata, necessitated by the optical structure of their eyeballs, and by the concave recipient surface of the retina.

In the non-Vertebrate Annulosa, *e. g.*, the eyes are convex, and images of surrounding objects, and also of the limbs and other appendages of the animal, are received in a true, and not in a reversed as well as an inverted position: those on the right-hand side of the animal, being received on the right-hand side of each eye, and those on the left, on the left-hand side, without inversion; in such animals, the motor apparatus is governed on its own side. In the Vertebrata, the right- and left-hand objects, and, therefore, the right and left limbs, are seen on the opposite sides of the eye; the guiding impressions thus perceived, pass over through the opposite side of the sensorium, and from thence, the motor stimulus again crosses the middle line in governing the movements of those limbs. In this way, the reversion of the visual impressions, necessitated by the structure of the eye, meets with a corrective action in the government of the limbs.

In the eyes of fishes, the sclerotic is very firm, and generally contains two cartilaginous plates; when, however, those are absent, the posterior fibrous part is of great thickness; in some fishes, indeed, the posterior part of the coat is one inch and a half thick; in certain large fishes, it forms even a bony cup, into which the cornea is fitted in front, and through an opening in which the optic nerve enters behind. By this great strength of the sclerotic, which reminds one of the similar provision in the whales, the sphericity of the posterior part of the eyeball is maintained. Sometimes a cartilaginous or tendinous pedicle connects the sclerotic with the bottom of the orbital cavity; in the skate, a distinct arthroidal articulation exists between the pedicle and the eyeball. The choroid coat is composed of several layers; the pigment, in the osseous fishes, has a silvery hue in its superficial fibrous layer, but is black or purple in its deeper layer; between these two layers, is a red horseshoe-shaped vascular organ, composed of tortuous bloodvessels, chiefly venous, and known as the *choroid gland*, the use of which is yet unexplained. Amongst the cartilaginous fishes, in the sharks and rays, the outer layer of the choroid pigment is of a dark color, and the deeper one has a metallic lustre. In the sturgeon, and also in some osseous fishes, there exists a fold of the choroid, forming the falciform process, on which is often found a branch of a ciliary nerve, expanded at its extremity, and forming the *campanula* (Haller.) The falciform process, like the pecten of birds, projects into the vitreous humor, and is fixed to the back part of the capsule of the lens. In the conger-eel, there are two such processes, by which the lens is suspended at two points. The iris, for the most part, presents a bright metallic lustre, and has a large, round, and slightly changeable pupil; the pupil has, indeed, been described as being quite motionless. The anableps is said to have a double pupil in each eye; in the rays, a broad black velum is found in front of the pupil. After death, the form of the pupil in the fish's eye is often very irregular. The retina usually reaches forwards to the border of the iris. It has been suggested, that fishes, living at a very great depth in lakes, or in the ocean, must be almost in a state of complete darkness; and that either their retinæ, with the plicæ upon the falciform process, must be endowed with an increased sensibility to light, or that they possess in their barbules, or other appendages, sensory organs of touch which compensate them for their inability to see.

In those Vertebrata which live in the air, the refracting powers of the eye depend largely on the cornea and aqueous humor combined; but in fishes, the action of these parts must be comparatively slight, as their refractive power is so little in excess of water, the medium from which the light immediately enters the eye. The cornea, indeed, in fishes, is very flat, and the aqueous humor is very much reduced in quantity, conditions the very opposite of those found, for example, in the far-seeing birds of prey; but the formation of distinct images, by bringing the luminous rays to an exact focus on the retina, is accomplished chiefly by the crystalline lens, which is accordingly of very large size, relatively to that of the entire eyeball, completely spherical, and unusually dense, its internal laminæ being almost as hard as horn. These characters impart high refractive power to the lens in fishes; its focus is accordingly very short, and hence the vitreous humor, like the aqueous, is scanty, and its form flattened, so that the lens is closely approximated to the retina; in front, too, the lens usually projects through the pupil into the anterior chamber of the eyeball. In the Surinam sprat, the eyes are situated quite on the upper part of the head, so that they are often somewhat above the surface of the water; the pupil is partially divided, and the lens is also composed of two portions, so that it is supposed that one part of this curious eye is adapted for aerial, and the other for aquatic, vision. There have recently been described by Leuckart, minute lens-like bodies, found in the colored spots upon the sides of the head and body of small fishes of the general Stomias and Chauliodus ; from the presence of these bodies, he regards the spots in question, as examples of true ocelli, or ocular spots; but this inference may be incorrect.

Amongst the Mollusca, the Cephalopods are remarkable for the great development of the eyes, which are larger than in any other non-vertebrate animals, and bear a closer resemblance to the organ of vision in the Vertebrata. The large spherical eyeballs, placed symmetrically on the sides of the head, are invested by a wide capsule formed by the integument, which is, at one part, transparent, and supplies the place of the cornea. This covering, however, is not completely closed, but presents an opening through which the sea-water enters, and fills up the space between the eyeball proper and the capsule, so that there is no aqueous humor. In Loligopsis and others, this opening is of very large size, and the anterior portion of the lens projects freely into the sea-water. The lens lies deeply embedded in the vitreous humor, and is divided into two unequal parts, one in front of the other, which are separated by a delicate interposed membrane, extending from the choroid. The anterior part is the smaller one. Each consists of a portion of a sphere, and their substance, though soft externally, is dense within, and contains a firm nucleus. The sphericity and density of the lens, suggest a resemblance to the lens of fishes, and are dependent on the same necessity of providing a refractive body of greater power than is needed in animals living in air. The double lens of the eye of a cuttle-fish is, indeed, an extreme example of such a provision. The choroid is of a dark color, and there is a well-developed iris, with a kidney-shaped pupil. By means of the ciliary processes, which are well developed, it is possible that the eye is accommodated to vision at different distances.

Amongst Pteropoda, the Clio has two eyes, which are placed behind the head, and somewhat resemble a bent cylinder. The Pulmo- and Branchio-gasteropods have, with but few exceptions, black points, or eyes, in the neighborhood of the œsophageal ganglion, situated, either at the base of the tentacles, as in Limnæus, in the middle of those parts, as in Halyotis, or at the apex, as in the genus Helix or Snail. These simple eyes are dark-colored elevations, covered by the soft skin of the tentacle, which constitutes a firm transparent cornea ; behind this, is a globular lens, a cup-shaped choroid membrane, sometimes ending in an iris-like ring, and an optic nerve, expanding into retinal elements. In the order of the Heteropods, the eyes are very largely developed. Of the Lamellibranchiata, which are acephalous, most are destitute of eyes. In some, however, rudimentary eyes are said to exist; these so-called *eye-spots* are situated, in the Pecten and others, on the margin of the mantle, between the tentacular appendages, and present the appearance of little shining pear-like bodies, supported on short movable pedicles, and having a pigment layer provided with a silvery stratum ; sometimes they are arranged singly, at other times, in groups of 20 or 30, close to each other. In the Tunicated Molluscoida, *pigment spots* are found on the central nervous ganglion, but no lens has been discovered in them.

From the preceding account, it appears that in the Molluscous Class, the eye is gradually simplified, in passing from the complex organ of the Cephalopods, through the simpler eyes of the Pteropods, Heteropods, and Gasteropods, to the still more simple eye-spots of certain of the Lamellibranchiata ; but, in all these cases, a special refractive body or lens is met with, so that perhaps more or less perfect images, at least of *near* objects, are formed, or, as especially occurs in the more simple forms, a mere concentration of luminous rays takes place, at the back of the eye. In the pigment spots of the Molluscoida, however, so far as is known, no lens exists, but merely pigmentary and nervous substance in close conjunction ; hence in these animals, sight must be supposed to be reduced to a mere appreciation of light and color, without any distinction of form whatever.

Amongst Insects, two kinds of eyes are found, the *simple* and *compound.* Usually both occur together, but some insects have only simple, and others only compound, eyes. The *simple* eyes, called *stemmata*, *ocelli*, or *eye-spots*, resemble, in a general manner, the organs of vision in the higher animals, and present the following structures, viz., a minute transparent cornea, close behind which, is a globular lens, resting upon a cup-shaped vitreous humor; on the posterior convex surface of the latter, a nervous filament spreads out, forming a retina; and surrounding the whole, is a choroid coat, which, passing on to the anterior surface of the lens, there forms a sort of pupillary aperture; the color of the choroid coat, and therefore of the ocelli, varies, but is more commonly dark. The *compound* or *facetted eyes* present quite a different structure. In the common cockchafer, for example, the optic nerve, given off by the supra-œsophageal ganglion, swells into a large segment of a sphere; from this part, an immense number of very short branches are given off, which spread out, behind a layer of pigment called the *common choroid*, into a membranous expansion named the *common retina;* from this retinal expansion, a multitude of filaments, corresponding in number to the facets of the cornea, are given off, which, after traversing the common choroid, spread out upon a number of hexahedral transparent prisms, covered in front with minute double convex lenses, the so-called *corneal facets* (Straus-Durckheim). The compound eye of the Libellula, or dragon-fly, consists of an immense multitude of very minute pyramidal tubes, the blunted apices of which are set closely together, on the bulbous extremity of the optic nerve; the base of each tube is turned towards the globular surface of the eye, and is invested by a hard facet or corneola, which forms a *meniscus* or *concavo-convex* lens; behind this, is a small cavity filled with an aqueous humor. Each tube is invested by a dark-colored layer of pigment, surrounding a clear fluid, which occupies the axis of the tube, and is supposed to correspond with the vitreous humor; in front, between the cornea and the vitreous humor, this pigmentary membrane presents a small pupillary aperture. The compound eye consists, therefore, of a combination of numerous minute independent eyes. The number of single eyes entering into the formation of the compound eyes, is, in some insects, very great; thus, in the ant there are said to be 50, in the common house-fly, 8000, in the dragon-fly more than 12,500, and in the Mordella beetle upwards of 25,000. The compound eyes are usually sessile, and form rounded eminences on the sides of the head, but sometimes they are supported on a pedicle or footstalk. They frequently present a brilliant color, such as a bright green, or green and purple, or even a pure gold color. It has been supposed that the simple ocelli of insects are adapted only for very near vision. The mode in which a visual image is formed by the remarkable compound or aggregate eye, is peculiar. Each minute eye must form an image of a corresponding portion of the visual field, for, owing to its tubular shape, and to the fact that it forms a radius proceeding from a convex surface, it seems probable that only those rays, which fall nearly vertically upon the minute corneal facet, can pass down it, whilst the lateral rays are more or less perfectly excluded. The multitude of separate images, like portions of mosaic, must be combined by the animal, into a single picture, for we cannot conceive that it sees objects multiplied. This act of combination must be a sensorial operation, accomplished in the cephalic nervous apparatus of the insect. The images, separate or combined, formed in such an eye, are not inverted from above downwards, or reversed from right to left, as in the Vertebrate eye, but occupy their normal position; there is no decussation of the optic nerves, and none of the great motor nervous columns.

The Orthoptera, Hemiptera, Neuroptera, Hymenoptera, and various other insects, have, in the perfect state, from two to three simple eyes, and also compound eyes; in such cases, the simple eyes are usually placed on the top of the head. In those insects in which simple eyes only exist, these are usually situated on the side of the head. When numerous simple eyes are grouped together into one mass, they form the *conglomerate* or *aggregate* eye. A few insects are destitute of eyes, such as the neuter Termites, and the Claviger beetle. In the greater number of the larvæ of perfect insects, simple eyes alone exist; thus the larvæ of the bee have two simple eyes; in the larvæ of the Dytiscus beetle, there are six on each side of the head. Some larvæ are destitute of eyes, as those of Hymenoptera.

The eyes of the Myriapoda, like those of all the higher Annulosa, resemble the eyes of insects; they consist, however, for the most part, of conglomerate, *i. e.*, of simple eyes grouped together; compound eyes are more rarely met with, and when they occur, are of large size. The common Millipede (Julus terrestris) has 28 eyes, placed in 7 rows, which form almost an equilateral triangle. Many Myriapoda are blind.

The Arachnida have only simple eyes or stemmata, but these are of very perfect structure; the pupillary aperture of the choroid is sometimes provided with muscular fibres, which enable it to be contracted. The number of these simple ocelli varies, being only two in the Chelifer and many mites, 4 in the Phalangia and other mites, 6 or 8 in the Araneida, and 10 in the Scorpion. When present in large numbers, they are often of different size in the same animal, and are either closely crowded together on the top of the head, or placed laterally on the cephalo-thorax, or even on the middle of the upper surface of the abdomen. The eyes of spiders are often very bright, and of a sapphire color; the peculiar glare of the eyes of some spiders and scorpions, depends on the difference in color between the circumference and centre of the eye, the former part being pale, and the latter dark. The eye of the Tarantula has a bright red centre, and an amber-colored margin. Many of the lower Arachnida have no eyes.

The Crustacea possess both simple and compound eyes. The simple eyes are never more than two or three in number; in some of the smaller Crustacea, however, as in Daphnia, a number of these are grouped together, forming a conglomerate eye, and are covered by a common cornea; they are, moreover, movable. The compound eyes resemble those of insects; but they are placed at the extremity of movable peduncles, at least in the highest Orders, so that they can be turned in any direction. The corneal facets are usually hexagonal; sometimes, however, they are square, as in the lobster and shrimp. Among some parasitic or fixed Crustacea, as in the Cirrhopods and others, eyes are entirely absent, but, even in these species, they are present in the larval stage.

The eyes in the Annelides are still more simple; they consist merely of an expansion of the optic nerve, covered by a transparent membrane, formed by the cuticle, and having behind it a layer of black pigment, sometimes perforated in its centre. In some species, a small transparent, spheroidal, refractive, body or lens is met with, as in Alciope, the Leech, the Nereids, and others; but a lens is not always present. The leech, Hirudo medicinalis, has ten eyes, which appear as small dark elevated dots, arranged in a semicircle on the fore part of the head; they have no pupil. The Eunice has four eye-spots on the posterior part of the body; in the Nereis, there are four arranged in a quadrangle on the surface of the head. In a curious worm, named the Polyophthalmus, besides a group of ocelli upon the head, there is found a succession of other smaller ones, arranged in pairs, one on each side of every segment of the long body; all of these eyes have a minute refractive body or lens. In cases where such a lens is wanting, the animals must be restricted to the mere capability of distinguishing light from darkness, and color without form. Even where the lens is present, it is doubtful whether any distinct image is formed, except, perhaps, for very near objects.

In the Annuloida, eye-spots are seen in the worm-like Scolecida, in the Rotifera, and in a few of the Echinodermata. In the first group, may be mentioned the Planaria and the larval stage of Distoma and Monostoma, but the Entozoa generally, are destitute of pigment spots. Amongst the Rotifera, most species have two ocelli, but in some they are combined into a single spot, resting on the centre ganglion of the nervous system, at the fore part of the body. In the Echinodermata, eye-spots are seen at the ends of the rays of a few star-fishes, and around the lower opening of the alimentary canal in some Echinida.

In a few of the Cœlenterata, pigment spots are present, either destitute of a lens, variously colored, and placed on the central nervous ganglion, as in

Beroe and other allied forms; or provided with a lens-like body, embedded in pigment, as in the red or yellow-colored eye-spots found around the borders of the mantle or disc in the Medusa, in immediate contiguity with the so-called auditory sacs, or lithocysts. Nervous filaments probably proceed to them.

In these cases, and in those Annuloida in which such pigment spots, though destitute of a refractive lens, are situated upon the central nervous ganglion, their sensory office can hardly be denied; and, as they occupy positions corresponding to the true ocelli provided with lenses, in other animals, their visual function, however feeble, is placed almost beyond a doubt.

In the Protozoa, pigment spots are only known to exist in certain Infusoria. As no nervous system has been demonstrated in these low unicellular animal organisms, it has been disputed whether in such creatures, the pigment spots are really visual organs. The undoubted influence of light upon these animals, attracting them, for example, to the light side of the vessel in which they are kept, may be owing to a sensibility inherent either in the sarcodous substance of their bodies, or in nervous granules connected with the pigment spots; or, as elsewhere remarked, such apparent attraction may be explained by the incidental action of the heat associated with the light.

SPECIAL PHYSIOLOGY.

THE VEGETATIVE FUNCTIONS.

THE functions to be considered under this head, are the *nutritive* and *reproductive* functions. The former include digestion, absorption, chylification, circulation, nutrition, reparation, sanguification, secretion, excretion, and respiration, together with the production of animal heat, muscular force, light, and electricity.

DIGESTION.

Amongst other phenomena produced by the waste of the solid constituents of the body, and the loss of the fluid, or watery part of the tissues, are the special sensations of hunger and thirst, which have their seat, like other sensations, in the nervous system, and the phenomena of which have been already explained (p. 349). These sensations of appetite, excite the desire to take food; and by the process of digestion, the food, thus taken, is prepared for absorption, and conversion into blood. The term *food* includes all substances, received into the alimentary canal, and used for the support of life, either by supplying the waste constantly occurring in the living animal tissues, or by affording materials for the maintenance of the temperature of the body. Food, therefore, contains substances which have a certain chemical relation to the tissues which it supports. These tissues, besides containing water and saline substances, are composed of proximate organic principles, having a highly complex chemical constitution (pp. 84 to 86). Food also consists, more or less, of substances having already the same, or a similar chemical composition: for the animal body, so far as is known, has no power of forming such proximate organic compounds out of their component elements, or from the simpler combinations of these.

Animals, indeed, are either carnivorous or herbivorous. The carnivorous, or flesh-devouring species, obviously live upon food possessing the same chemical composition as the fluids and tissues of their own bodies; and as regards the herbivorous, or vegetable-feeding animals, their food also contains proximate principles, closely resembling those which exist in the animal body. Whatever the nature or source of the food of Animals, its proximate principles are, therefore, chemically similar; and it is to the Vegetable Kingdom that we must attribute the power of chemically combining, under the agency of solar light and heat, the elements derived from the simpler combinations of inorganic nature, into those complex organic proximate principles which, thus elaborated in the living tissues of vegetables, constitute the nutriment of Animals. Hence, the Vegetable Kingdom derives its nourishment from, and depends upon, the Mineral Kingdom; the Animal Kingdom derives its nourishment from, and depends upon, the Vegetable Kingdom; whilst the decaying portions of the Vegetable Kingdom which are unconsumed by animals, and the particles of the bodies of animals which undergo change during life, or decomposition after death, revert to the simpler chemical compounds of inorganic nature, which, again, under the influence of the vito-chemical forces of the plant, are reintroduced into the stream of organic existence.

Sources, Varieties, and Nature of Human Food.

The food of Man may be either *solid* or *fluid.* If solid, it may be *hard*, so as to require to be broken by mastication, or *soft*, so as merely to need subdivision, before it is swallowed. Again, food may be derived from the *inorganic* or from the *organic* world; or it may be classified according to its source, whether this be *mineral*, *vegetable*, or *animal.* Thus, the alkaline and earthy salts, the traces of iron, sulphur, and phosphorus, and the large quantity of water, are derived from the *mineral* kingdom. *Vegetable* food includes the roots, stems, leaves, fruits, and seeds of plants; also certain products of vinous decomposition, as the various alcoholic beverages, and lastly, condiments, vegetable acids, and vinegar or the product of the acetous fermentation. *Animal* food consists of all the digestible parts of animals, in which is comprised nearly every tissue, with the exception of the horny textures and the hair, even the bones yielding nutriment on being boiled. Besides this, eggs and roe, milk, butter, buttermilk, curd, cheese, and whey, are comprehended in this category.

The *chemical constitution* of food, however, is the point to which the greatest significance is to be attached; and the most useful classifications are founded on a consideration of the different nutrient proximate chemical principles which it contains. Thus regarded, the multitudinous articles of diet consumed by man, under his extremely varied conditions of life, dependent on climate, social condition, national custom, or individual habit, consist of a comparatively small number of proximate chemical constituents. The importance of these chemical distinctions of the food, was clearly indicated by Prout, and has been since established by the researches of Liebig, and many other chemists. Prout divided all nutrient substances into *albuminous* bodies, such as the albumen, fibrin, and casein of animals, and the gluten and legumin of plants; *oleaginous* substances, including the animal and vegetable fats and oils; and *saccharine* matters, comprising the various kinds of sugar. According to him, the typical form of animal food, is that supplied, by nature, to the young of mammiferous animals and man, viz., *milk*, in which fluid, casein represents the albuminous kind of nutritive substances; butter, the oleaginous kind; and sugar of milk, the saccharine kind. Besides these, milk also supplies water, and the mineral matters essential to the formation of the tissues.

A more exhaustive classification of the nutritive substances contained in food, is that which follows:

1. *Albuminoid* substances. From the animal kingdom, *albumen*, whether derived from the white of eggs, from blood, or from the muscular or nervous tissues; *syntonin*, or the fibrinous element of muscle, some of which is contained in the expressed juice of meat; *globulin*, *cruorin*, and *fibrin*, from the blood; *casein*, derived from milk; and the *vitellin* of the yolk of eggs. The substance of the liver, pancreas, kidneys, and other glands, is also, in great part, albuminoid, mixed, however, especially in the first organ, with fat. The brain substance is also highly nutritive, containing both albuminoid and fatty matter. In this group, must be included, not only cruorin, or the coloring matter of the blood, but also *myochrome*, or that of muscle, both of which have an extraordinary affinity for oxygen. From the vegetable kingdom, are obtained the albuminoid substance *gluten*, sometimes called *vegetable albumen*, which is chiefly obtained from the seeds of the various kinds of corn, and other grasses; also *legumin*, which has been compared to animal casein, and exists in large quantity in the seeds of peas, beans, lentils, and other leguminous plants. Vegetable albumen likewise exists, in small quantity, in the growing or soft tissues of the various succulent edible parts of vegetables and fruit, such as the cabbage, cauliflower, turnip, apple, pear, and orange.

2. *Gelatinoid* substances. These, which are derived solely from the animal kingdom, include *jelly* of various kinds, obtained from the gelatin-yielding tissues of animals, such as isinglass, which is the dried sound, or air-bladder, of the sturgeon, the areolar and fibrous tissues, tendons, and bones; also *chondrin*, or the jelly obtained from cartilages. These several tissues, however, are not supposed to contain gelatin or chondrin, when in their raw or uncooked state. Gelatinoid substances are present in broths, jellies, and ivory bone-dust. So far as their nutrient qualities are concerned, they must be distinguished from the albuminoid substances.

3. *Oleaginous* substances. These comprehend the animal fats and oils, *stearin*, *margarin*, *palmitin*, and *olein*, the fatty matters of the bile and of the brain, and those of the yolk of eggs; and also the fatty acids of butter, the butyric, capric, and caproic. To these must be

added, the vegetable oils, whether solid or fluid, such as cocoa-nut oil, olive oil, and almond oil.

4. *Amylaceous* or *starchy*, *gummy*, and *saccharine* substances. These comprehend the different varieties of *starch*, such as potato starch, arrow-root, sago, tapioca, rice, and the starchy portion of wheat and other grain. The gummy substances include, besides all the natural *gums* and mucilages of fruits and vegetables, the substance named *dextrin*, which results from the transformation of starch, *cellulose* or lignin, and also *pectin*, a constituent of succulent vegetables. The *sugars* are the common, or cane sugar, and grape sugar, derived, as such, from vegetables, or produced by the transformation of starchy or gummy substances. There are also the sugar of honey, which is an animal preparation; the glycogen, or animal starch, often present in flesh, but chiefly found in the substance of the liver; *inosite*, or sugar of muscle; and lastly, the sugar of milk, *lactose*, or *lactin*, which, though usually formed in the animal economy, can also be artificially made, by acting upon starch with certain acids, at a high temperature.

5. *Stimulating* substances. These consist of three classes: viz., first, the various kinds of *spices* or condiments, the active properties of which depend usually upon volatile or essential oils; secondly, the parts of vegetables, whether the leaves or berries, which contain the *alkaloids*, thein, caffein, or theobromin, which are found in tea, coffee, cocoa, and the Paraguay tea. With these should probably be associated, the substances named *extractives*, viz., *cerebric acid*, which exists in nervous substance, and also in corn, especially in Indian corn; *creatin* and *creatinin*, which are found in the juice of meat, in the brain, and in the blood, the former being converted in the system into the latter; both of these act either as stimulants, or by retarding chemical change and loss in the albuminoid tissues. The thein and allied bodies certainly stimulate the heart, muscles, and nervous system. Thirdly, there are the various *alcoholic* beverages made by the fermentation of saccharine substances, such as mead, beer, cider, wine, and the stronger alcoholic fluids or spirits distilled from various fermenting saccharine vegetable juices. These substances are probably not immediately nutritive, or able to supply the waste of material, but appear rather to act as stimuli to the nervous system, and also by preventing waste. To these may be added, the several *ethers* formed in ripe fruits, and in wines, from the action of the organic vegetable acids on alcohol. This class may also include certain *organic vegetable acids*, such as the acetic acid of vinegar, the tartaric, malic, racemic, oxalic, and citric, derived respectively, from grapes or raisins, apples, goose berries, the esculent rhubarb, and the lemon, lime, and orange; and lastly, the lactic acid existing in sauer-kraut, and in fermented cucumbers or beans, all of which are favorite articles of diet with some nations. The prevalence of the desire for acids with the food is remarkable. Lactic acid also exists in sour milk, which is much consumed, and in the juice of meat, together with paralactic and inosinic acids.

6. *Saline*, *earthy*, and *mineral* substances. These, which are, in certain proportions, essential articles of food, soda for the blood, potash for the muscles, and lime for the bones, consist of the chlorides of

sodium and potassium, the phosphates of soda, potash, and of magnesia, perhaps the alkaline sulphates, the phosphate and carbonate of lime, and oxide of iron. Minute traces of manganese and silica are also necessary, the latter being probably combined with fluorine. Such substances as alumina and copper are probably adventitious ingredients, and of no essential importance as food.

7. *Water* is the most abundant constituent of the animal body, and is a most essential article of food. From the many offices which it performs, dissolving the food, rendering it capable of absorption and entrance into the circulation, facilitating all nutritive, secretive, and excretive processes, and lastly, maintaining the due elasticity and flexibility of the tissues, and their susceptibility of vito-chemical changes, water may be regarded as a common vehicle, in which all other articles of diet are conveyed into, through, and from the animal economy.

The albuminoid and gelatinoid nutrient substances, resemble each other very closely in composition; in addition to carbon, hydrogen, oxygen, and sulphur, they contain nitrogen, and have therefore been named, *nitrogenous* or *azotized* food; and, as these substances are especially concerned in the formation of the albuminoid and gelatin-yielding tissues of the body, which indeed cannot be built up without them, they have been designated *nutritive* or *plastic* food. Moreover, as they supply the waste which takes place in the muscular and other tissues, they have been likewise called *flesh-forming*, *tissue-forming*, or *histo-genetic*, food. On the other hand, the oleaginous and saccharine substances are composed of carbon, hydrogen, and oxygen only, and are therefore named *non-nitrogenous* or *non-azotized* food. The starchy, saccharine, and allied compounds form the carbhydrates; whilst the fatty substances, still richer in carbon, are named hydrocarbons. As neither of these is ever supposed to be convertible, by the addition of nitrogen, into nitrogenous, plastic, or flesh-forming food, but rather, owing to their richness in carbon and hydrogen, and their poverty in oxygen, to be ultimately used for the purposes of maintaining the animal heat, either being first stored up in the body as fat, or being at once oxygenated through the respiratory process, they have been classed together under the appellation of *respiratory*, *calorific* or *heat-forming*, food.

These distinctions, which have been chiefly explained and advocated by Liebig, undoubtedly represent a general truth; but they must be accepted with certain qualifications. In the first place, albuminoid substances may, it would seem, undergo metamorphosis, in the living body, into fatty or even starch-like substances, and so may nourish non-nitrogenous, as well as fleshy or nitrogenous, tissues. Moreover, the nitrogenous tissues of the living body, especially those of the muscles and brain, themselves undergo a most active waste, *i. e.*, a chemical decomposition, of which the essential feature is oxidation; so that, to a certain extent, they too, in being decomposed, must contribute to the evolution of heat, subserve the respiratory process, and so far act as respiratory food.

Again, chemical analysis shows, that in the brain especially, but also in muscular tissue, fatty matter is an important constituent, essential, indeed, to the composition of those tissues; moreover, starchy and saccharine matters exist in certain organs, and are convertible, in the living economy, into fat; hence the non-nitrogenous, oleaginous, and saccharine substances must, also, be regarded as nutritive or plastic food. Even in young growing animal cells, fatty matter appears to be an essential element. Again, as regards gelatin, and the gelatin-yielding tissues, which, though they contain nitrogen, have a lower chemical constitution than the albuminoid substances, it is not certain that they are convertible into, or capable of being made use of as, nutriment for the living tissues. It is now generally denied that they can be so converted into, or assimilated by, tissues which, like muscle and nerve, contain syntonin and albumen; it is even doubted whether they can be directly assimilated as nutriment, even by the living gelatin-yielding tissues themselves, which, of course, have an identical chemical composition. Such substances may, therefore, possess very limited or no nutritive or plastic qualities; and may merely be oxidized in the system, like the non-nitrogenous, respiratory food. The precise destination of the several elements of food is, however, not completely understood; but neither of the two kinds of food, the nitrogenous, or the non-nitrogenous, is alone adequate to support animal or human life; for perfect nutrition, the two must be taken together in certain proportions.

The chemical composition of most of the nitrogenous and non-nitrogenous proximate constituents of animal substances used as food, is given in the tables at pages 84 and 85. The closely similar composition of the nitrogenous and non-nitrogenous proximate constituents of vegetable substances used as food, is illustrated in the annexed table (p. 486).

Prehension and Preparation of Food.

In the lower animals, the important act of the prehension of food is provided for, in every case, with the most admirable perfection of contrivance. In Man, however, the arm and hand are so wonderfully organized for other, and higher, purposes (p. 193), that their prehensile action, in the gathering, or preparation, of food, and its conveyance to the mouth, are, though essential, only subordinate offices of the upper limb. The lips and tongue, which, in the Mammalia, are devoted, mainly at least, to the taking of food, are in Man also so employed; but higher services are demanded of these parts, and we are accustomed to associate their mechanism more especially with the faculty of speech. Lastly, the jaws and teeth, although, in animals, they frequently constitute the most important, and, in the case of the lower Vertebrata, the sole organs of prehension, can hardly be said to fulfil, in Man, in addition to their proper office of mastication, a prehensile office in reference to the food.

As regards the prehension of food, Man appears, indeed, almost at a mechanical disadvantage, in comparison with the animals beneath him, so far at least, as concerns any special adaptation of the parts of

ANALYSIS OF VEGETABLE PROXIMATE CONSTITUENTS.

	Carbon.	Hydrogen.	Nitrogen.	Oxygen.	Sulphur and Phosph.
Vegetable Albumen, ... =	55.01	7.23	15.92	21.84	Included with the oxygen.
Vegetable Fibrin or Gluten, . . =	54.6	7.2	15.81	22.29	
Legumin, a similar composition, but not well determined.					
Thein, Caffein ($C_8H_{10}N_4O_2$), . . =	49.4	5.2	28.9	16.5	
Theobromin ($C_7H_8N_4O_2$), . . . =	46.7	4.4	31.1	17.8	
Vegetable Oils, chiefly Oleic acid, and Glycerin (p. 84).					
Starch, ... ; Dextrin or Gum, . . ; Cellulose and Lignin, } ($C_6H_{10}O_5$), =	44 4	6.2		49.4	
Cane Sugar ($C_{12}H_{22}O_{11}$), . . . =	42.1	6.4		51.5	
Grape Sugar, Glucose, or Dextrose. } ($C_6H_{12}O_6$), =	40.	6.7		53.3	
Alcohol (C_2H_6O), ... =	52.2	13.		34.8	
Ether ($C_4H_{10}O$), ... =	64.85	13.5		21.65	
Vegetable Acids:					
Citric ($C_6H_8O_7$), ... =	37.5	4.2		58.3	
Malic ($C_4H_6O_5$), ... =	35.8	4.4		59.8	
Tartaric ($C_4H_6O_6$), . . . =	32.	4.		64.	
Alkaline and Earthy Salts and Water, the same as in Animals; but Land Plants contain mostly Potash, and Marine Plants mostly Soda.					

the organism employed for that purpose in animals. Nevertheless, he accomplishes this act with facility.

In the choice and selection of food, Man, guided by his intelligence, possesses enormous advantages over the lower animals. He ranges through the whole domain of the organic kingdom, and by the arts of acclimatization, breeding, cultivation, and agriculture, has improved many species, both animal and vegetable, which, in their wild and uncultivated condition, are much inferior as sources of food. The improvement of the cereal, or corn plants, of vegetables and fruits, and of the ox, sheep, and pig, and also the acclimatization of many gallinaceous birds, and the more recent results of pisciculture, and of attempts to breed the oyster, afford proofs of this statement.

The use of *fire* for the preparation of food, is, like the employment of fire in general, peculiar to Man, who has, indeed, been designated a "cooking animal." The direct application of fire heat to food, develops peculiar empyreumatic flavors and odors, in the cooked substance, whether this be animal or vegetable; but the more important action of heat, whether applied directly, as in roasting or baking, or indirectly, through the agency of water, as in boiling, is to change the molar and molecular condition of the cooked substances. Thus, the albuminoid bodies are more or less coagulated; the gelatin-yielding tissues become swollen and partially gelatinized; fat-cells are ruptured, and fats are rendered more fluid; the various kinds of starch have their granules pulpified, and the cellulose and lignin of vegetable tissue, are broken up, so as to liberate the contents of the cells. The general result of cooking is to disintegrate, and separate the animal tissues into minuter portions, and to destroy the continuity of vegetable textures. Cooking, therefore, produces both physical and chemical changes in the food, the tendency of which is to facilitate mastication, and the subsequent action of the digestive fluids, thus rendering them softer and more digestible.

Man also has discovered and employed as drinks, numerous beverages, obtained from the natural products of nearly every climate, by the spontaneous, or the induced, alcoholic fermentation of saccharine matter, whether this saccharine matter exist ready formed, as in the juice of the grape, or other fruits, or whether it be artificially generated by the transformation of starch into sugar, as happens when barley is manufactured into malt. Besides consuming the immediate products of fermentation, in the shape of wine, beer, and other fermented liquors, distillation is had recourse to by Man, in order to procure, in a more concentrated state, the spirit, or alcohol, generated in that fermentation. Man, therefore, not only employs the art of cooking, but also the chemical processes of fermentation and distillation, in the preparation of food, using this term in its widest sense. The precise destination of alcohol in the system will be hereafter discussed.

Other beverages are made by simple infusion or decoction, so as to dissolve out certain nutrient or stimulating substances, as from tea, roasted coffee, cocoa, and other vegetable products. Sugar is used in solution, in the sweetening or preservation of fruits, in cookery, and in preparing various articles of confectionery; it is a highly important and useful form of food. Common salt, being contained in the blood and tissues, is an essential article of food. Its use as a condiment, and also as a preservative, especially of animal substances employed as food, is very old and general. All animals are fond of salt. Its injurious influence on the quality of the food preserved in it, has long been recognized, the continued use of such food, in the form of salted provisions, favoring the production of scorbutus or scurvy. Salt hardens the muscular and other tissues preserved in it, by abstracting water from them; with this water, which appears in the brine, the soluble potash and magnesia salts, as well as the creatin and other extractives, are likewise abstracted from the meat, and pass into the preservative liquor, thus leaving the meat destitute of many alimentary principles essential to health. Indirectly, this may be the cause of scurvy; or that disease may partly depend on the direct action of the common salt taken in excess.

The employment of vinegar as a condiment, and the use of vegetable acids, those universally favorite articles of diet, aid in the solution of nitrogenous food, and possibly of the lime salts, but they can scarcely be regarded as possessing positive nutrient properties. Other condiments, and spices, serve to stimulate the secretion of the digestive fluids, and excite the movements of the alimentary canal.

In the artificial preparation of food, so as to render it soluble, or more easy of solution, we assist the digestive function itself, which, in adapting nutrient substances, by a series of processes, for absorption into the tissues of the body, has, for its immediate aim, the minute *subdivision* and the *solution* of these substances.

The process of digestion, accordingly, includes certain *mechanical* and *chemical* acts. The former have for their object, to triturate and comminute the food, to mix it with fluids and with the various secretions in the alimentary canal, to move it within and onwards through the several portions of that canal, and lastly, to expel from the body the unabsorbed residue. The latter are accomplished by the aid of the various digestive fluids poured into the alimentary canal. Considered in the order in which they take place within the body, the several processes necessary to digestion, are *mastication*, or the chewing of the food, and *insalivation*, or the mixing it with saliva, which occur simultaneously in the mouth; *deglutition* or *swallowing*, in which the food is conveyed through the pharynx and œsophagus, into the stomach; *gastric digestion*, which takes place in the stomach, by aid of the gastric juice, also called *chymification*, and sometimes, though erroneously, digestion proper, for further true digestive processes occur in the intestine; and, lastly, *intestinal digestion* itself, accomplished by aid of the bile, pancreatic juice, and intestinal juice, immediately preparatory to the proper act of absorption of the digested materials, by the lacteals, in which they appear as *chyle.* Absorption of certain constituents of the food, however, likewise occurs, more or less, through the capillaries of every part of the alimentary canal. The residue of the food, or *ingesta*, together with the unabsorbed secretions, form the *egesta*, the expulsion of which, constitutes the function of *defecation.*

The mechanical and chemical processes of digestion, require separate and lengthened consideration.

MECHANICAL PROCESSES OF DIGESTION.

Mastication and Insalivation.

The parts concerned in mastication, are the *teeth* and *jaws*, the *muscles* which move the lower jaw upon the upper one, the *muscles* of the *cheeks*, the *lips*, the *tongue*, and *palate.*

The *teeth* in Man, as in all Mammalia, are developed in two sets; a *first*, less numerous, and smaller *set*, known as the *milk*, *temporary*, or *deciduous teeth*, and a *second set*, larger and more numerous, called the *permanent teeth.*

The *milk* teeth are twenty in number, ten in each jaw. The five teeth, in either half of each jaw, commencing at the middle line, consist of two so-called *incisor* teeth, one *canine*, and two *molar* teeth. The formula of these teeth is thus written,—

$$\frac{M2 \quad C1 \quad I4 \quad C1 \quad M2}{M2 \quad C1 \quad I4 \quad C1 \quad M2}.$$

When these teeth are shed, they are succeeded, at intervals, by the *permanent* teeth, which are thirty-two in number, sixteen in each jaw, eight in either half of each jaw; viz., commencing at the middle

Fig. 84.

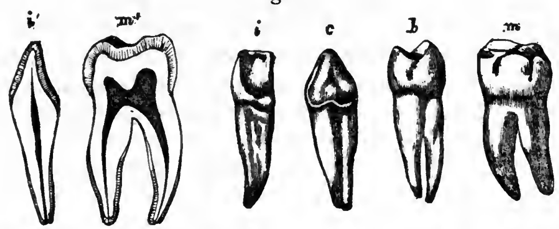


Fig. 84. Human teeth. *i*, lower lateral incisor, seen from behind. *c*, lower canine, seen from within. *b*, second upper bicuspid, seen sideways. *m*, second lower molar, seen from without. *i'*, section of an incisor tooth, showing the pulp cavity, extending from the point of the fang, the dentine, or tooth substance, the enamel on the crown, and the layer of cement on the fang. *m'*, section of a molar tooth, showing the same parts, and the pulp cavity extending into each fang. (Blake.)

line, two *incisors*, one *canine*, two *bicuspids*, and three *molars*. The formula of these teeth is therefore,—

$$\frac{M3 \quad B2 \quad C1 \quad I4 \quad C1 \quad B2 \quad M3}{M3 \quad B2 \quad C1 \quad I4 \quad C1 \quad B2 \quad M3}.$$

Each tooth, Fig. 84, *i* to *m*, consists of an exposed part, called the *crown* or *body*, and of a part buried in the gum and jaw, named the *root* or *fang;* at the junction of the crown and fang, is the slightly constricted *cervix* or *neck*. The several kinds of teeth differ in the form of their crowns, and in the number of their fangs; hence their different designations. The *incisor* teeth, *i*, have wide, thin, crowns, slightly convex in front, and smooth or marked with longitudinal furrows, but somewhat concave, or bevelled off, on their hinder surface; their edges, which, at first, present three small prominent points, are, when worn, long, narrow, and chisel-shaped, being well adapted for *cutting* purposes; hence their name. The fang is long, single, and somewhat compressed from side to side. In the temporary teeth, but much more markedly in the permanent set, the upper incisors are larger, and occupy more space transversely, than the lower ones; in the upper jaw, the middle incisors are larger than the lateral ones; in the lower jaw, the reverse is the case. The *canine* teeth, *c*, larger and thicker than the incisors, are distinguished by the pointed character of their crowns, which are very convex in front, and a little hollowed behind, and also by the great size and length of their single fang, which presents, on its sides, a slight longitudinal furrow. The upper canines, popularly called the *eye-teeth*, are larger and longer than the lower ones, and on their posterior surface, close to the gum, is found a minute tubercle. The groove on the fang, and this posterior tubercle, foreshadow the subdivided fang and double crown of the bicuspid teeth. The canine teeth are so named from their large size in the dog, though they are still larger in the great feline animals; in Man, they are more uniform in size with the neighboring teeth, than in the larger Quadrumana and Carnivora. From their single point or *cusp*, which wears down with use, these teeth are sometimes called the *cuspidate* teeth. The *bicuspid* teeth, *b*, sometimes called *premolars*, because they are placed before the molars, and also named the *small* or *false molars*, have a double crown furnished with two pointed cusps or tubercles; viz., an outer higher, and an inner lower one, between which is an irregular depression. The summit of the crown is quadrangular, and compressed from side to side, contrasting with the pointed canines, and chisel-shaped incisors. The fang, in the lower bicuspids, is deeply grooved on each side, but in the upper ones, is cleft for a certain distance at the point. The *molars* or *grinding* teeth, *m*, are the largest of the entire set; the first on each side of each jaw, are the largest, and the third, or last molars, which are also named the wisdom teeth (dentes sapientiæ), from their late appearance, are the smallest. They have a large, nearly cuboid crown. In the upper molars, this presents four cusps or tubercles, placed at the angles of the upper surface, and separated by a crucial depression; the first and second of these teeth have the internal anterior tubercle always the largest; in the last upper molars, the two internal tubercles are blended. The crowns of the lower molars are larger than those of the upper, and are distinguished by having a fifth small cusp or tubercle placed between the outer and inner posterior cusps, rather nearer to the former than to the latter; this fifth cusp is best marked in the last lower molar tooth. The grinding surface of the lower molars is nearly square; that of the upper, rhomboidal. In the lower jaw, the two anterior molars have two fangs, but these are broad, grooved on their surface, and sometimes subdivided at their points. In the upper jaw, the fangs of the two anterior molars are three in number, two outer and one inner fang, the latter being sometimes grooved or even subdivided. The fangs of the upper molars are more divergent than those of the lower ones. In the *wisdom teeth*, or *last* molars of each jaw, the fangs are generally *connate* or united into a mass, showing marks of subdivision into two fangs in the lower teeth, and three in the upper.

The row of teeth, in each jaw, forms what is called the *dental arch*. In Man, it presents a broad, even curve, the upper dental arch being larger than the lower, so that usually it overlaps the latter when the teeth are closed, and thus saves the edges of the incisor teeth from unnecessary wear. The upper front teeth are inclined slightly forwards, and the back teeth outwards; whilst the lower front teeth are vertical, and the lateral teeth directed somewhat inwards, an arrangement which corresponds with the greater size, and the overlapping of the upper dental arch. In Man, the entire series of teeth are characterized by being uninterrupted by any marked interval, hiatus, or *diastema*, and by their nearly even height, which however diminishes slightly from before backwards. In Mammiferous animals, the teeth are either of unequal height at different parts of the jaw, or are interrupted by larger or smaller intervals, or diastema.

The *temporary* teeth, though of course, in each case, of smaller size, have forms like those of the permanent teeth of the same name. The crowns of the incisors are chisel-shaped, those of the canines pointed, and those of the molars square, and provided with several cusps. The first upper molar, the largest of all, has three cusps, and the second four; the first lower molar four, and the second five. The fangs of the temporary incisors and canines, are single; those of the lower molars are two in number; those of the upper, three. In both jaws, they are more divergent than those of the permanent teeth.

The hard mass of a tooth is hollowed out, so as to form a cavity, called the *pulp cavity*, because, during life, it contains a soft substance named the *pulp*. This pulp cavity, Fig. 84, *i'*, *m'*, varies in shape with that of the tooth; it occupies the base of the crown, and is prolonged down each fang, in the form of a small canal, which opens at the point. The pulp consists of areolar tissue, supplied with vessels and nerves, which enter at the minute opening at the point of the fang; it is the remains of the vascular and nervous papilla, upon which the tooth is originally formed.

The hard portion of the tooth surrounding the pulp, is composed of three substances; viz., the *tooth substance*, *ivory*, or *dentine*, the *enamel*, and the *crusta petrosa*, or *cement* (see Fig. 84).

The dentine forms the greater part of the tooth, immediately surrounds the pulp cavity, and corresponds, in form, with the tooth itself. Its hardness is owing to the large quantity of earthy matter which it contains, its chemical composition being 72 parts of earthy to 28 of animal matter; whilst ordinary bone shows a proportion of $66\frac{1}{2}$ to $33\frac{1}{2}$. The earthy salts contain 66.7 of phosphate of lime, 3.3 of carbonate of lime, 1.8 of phosphate of magnesia and other salts, and some traces of fluoride of calcium. The animal substance is converted into gelatin on being boiled.

The dentine consists of microscopic tubes, called the *dental tubuli*, which have hard walls, and are embedded in an intermediate hard substance. These tubuli, originally described by Leeuwenhoek, commence by minute orifices on the walls of the pulp cavity, and proceed outwards in a slightly wavy course, close together; they soon divide dichotomously, and reach the superficial portion of the dentine, near the surface of which they terminate in fine branches, in loops, or in minute dilatations from which still finer branches proceed, or else in minute *dentinal cells.* The diameter of the inner or larger ends of the tubes, is about the $\frac{1}{4500}$th of an inch; their terminations are immeasurably fine. These tubuli might be compared to extremely minute Haversian canals, their finest terminal ramifications to the canaliculi, and the minute dentinal cells to the corpuscles or lacunæ of bone (p. 46). The dentine is, indeed, regarded as modified bone. In Man, the dentinal cells are few in number, and very minute, so that their similarity to the lacunæ of bone is not so striking as it is in the teeth of the horse and other animals, in which they are larger and more numerous. In the recent state, the dental tubuli are occupied by minute processes of the tooth pulp, which serve the purposes of nutrition, and perhaps also impart sensibility to the dentine. The substance of the walls of the tubuli, is comparatively thick; its structure is not exactly known. The intermediate hard, or so-called *intertubular*

Fig. 85.

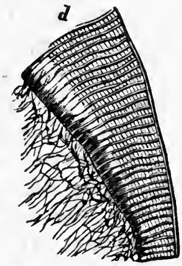


Fig. 85. Section of a portion of the crown of a tooth, magnified about 300 diameters. *d*, the enamel, composed of wavy fibres, marked with faint cross lines; the surface is bounded with a fine homogeneous layer. Beneath the enamel, is a portion of the tooth substance, showing the ends of the tubercle of the dentine, and certain irregular spaces in it. (After Kölliker.)

substance, is slightly granular, and contains the greater part of the earthy matter. When this is removed by an acid, the softened animal basis is said, by some, to consist of fibres running parallel with the tubes, by others, of minute corpuscles, arranged around the tubes, and, according to another view, of fine lamellæ disposed concentrically around the pulp cavity, across the direction of the tubules, which are supposed to perforate the lamellæ.

The *enamel*, the hardest of the dental substances, and, indeed, of all known animal textures, is the dense white covering, which protects the crowns of the teeth; it is thickest on the edges of the incisor and canine, and on the crown of the molar teeth, and gradually becomes thinner towards the neck, where it terminates. It contains more earthy matter than any other animal tissue, viz., 96.5 per cent., of which 89.8 are phosphate of lime, with traces of fluoride of calcium, 4.4 carbonate of lime, and 1.3 phosphate of magnesia and other salts. The animal matter amounts to 3.5 per cent., the analysis showing a loss of 1 per cent. (Bibra.) Berzelius estimated the animal matter at the remarkably low proportion of 2 per cent.

The enamel, Fig. 85, *d*, is composed entirely of microscopic hexagonal prismatic fibres, or rods, arranged closely together upon the dentine; they are fixed, by one extremity, to minute depressions on the surface of the dentine, and following a somewhat wavy course, present, at their outer ends, the appearance of a hexagonal mosaic pattern, where they form the free surface of the enamel. On the crowns of the teeth, the enamel fibres are vertical; on the sides, they become first oblique, and then horizontal. Their diameter is $\frac{1}{5500}$th of an inch. Near the surface of the dentine, minute interstices are found between the enamel fibres, supposed to be for the purpose of nutritive permeation. In the growing tooth, by the action of an acid, the enamel may be separated into its microscopic elements, viz., into delicate prismatic nucleated cells, the walls of which coalesce, and which form moulds for the deposit of the earthy matter. In the perfectly developed tooth, the thin parietes of the cells become almost, or entirely, absorbed, and the prismatic earthy casts are blended together as the enamel fibres. On treating a growing tooth with an acid, an exceedingly delicate membrane or cuticle is found, covering the entire surface, which afterwards becoming calcified and coherent with the ends of the subjacent fibres, forms an impenetrable protective covering to it.

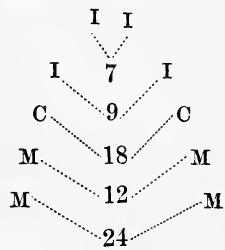
The *crusta petrosa*, or *cement*, Fig. 84, *i'*, *m'*, is a thin layer of true bone, which covers the fang, being thinnest next to the enamel, and thickest along the grooves and near the point; it becomes thicker in advanced age, and sometimes fills up the minute opening leading into the pulp cavity. The crusta petrosa contains lacunæ and canaliculi; the latter in the deep layers, sometimes anastomose with the terminations of the dental tubuli; in its thicker portions, it contains Haversian canals, surrounded by concentric lamellæ. Its outer surface is firmly attached to a fibro-vascular and sensitive membrane, called the *periodontal membrane*, which is analogous to a periosteum, and serves to fasten the teeth in the alveoli or sockets of the jaw, being itself united to the periosteal membrane which lines the sockets.

The dentine gives strength and solidity to the teeth, but being penetrated by processes of the sensitive pulp, and doubtless subject to nutritive changes, it is liable, when exposed, to suffer pain, and to undergo a process of decay resembling *caries*, which may even be repaired by an exudation of dense irregular dentinal substance. The dentine, though very hard, would not bear constant attrition; hence that singularly hard organized product, the enamel, is provided as a covering to the exposed parts of the teeth. This enamel, however, wears down, as is well seen in the incisor teeth, the primitively sharp, wavy, or notched edge of which soon becomes worn to an even chisel-like border. The enamel often exhibits minute fissures, and, in the depressions between the cusps of the molar teeth, deep cracks, which are the usual seat of commencing caries in the subjacent dentine. As life advances, the crusta petrosa often forms little knobs of bone upon the fangs of the teeth; and after a certain age, a deposit, partly resembling dentine and partly bone, named *osteo-dentine*, or *secondary dentine*, is sometimes slowly formed in the tooth cavity, whilst the pulp itself necessarily wastes. This deposit is produced, by a conversion of the pulp, and serves to strengthen and solidify the tooth, as its crown is being worn away; in time, however, this process ends by cutting off the vascular supply of the pulp, and leads to that final stage, in which the remaining parts of the teeth drop out, and leave the edentulous jaw of old age.

The teeth of Man, and of the Mammalia generally, are not parts of the endo-skeleton, but appendages developed in the mucous membrane of the mouth, which, like the armor-plates of the armadillo, the bony scales of the crocodile, and the scales and spines of fishes, all appendages of the skin, belong to the exo-skeleton, or dermal skeleton.

The mode of development of the teeth, and the manner in which the milk teeth are shed, and the permanent teeth are cut, will be described in the section on Development. The period of the *cutting* or *eruption* of the temporary teeth is as follows:

The milk teeth begin to appear at about the seventh month, and are completed at the expiration of the second year; but considerable difference exists in regard to the precise periods of their eruption, frequently the first teeth appearing as early as the fifth or sixth month, and some infants being born with teeth. The annexed diagram shows the usual order and average time at which the milk teeth are cut, the numbers indicating *months*.



The lower middle incisors appear first, and generally the lower teeth are cut before the corresponding teeth of the upper jaw. Before the cutting of the teeth, the edges of the jaw, previously sharp, hard, and pale, become rounded and swollen, and of a darker color, and the apex of the future tooth appears, like a white line or spot, through the gum.

The milk teeth, having, for a time, fulfilled the office of mastication, fall out, and are succeeded by the permanent set, destined to serve the same purpose through the remainder of life. Teeth, once formed, cannot increase in size. The milk teeth, though sufficiently large for the infantile jaws, and strong enough to resist the action of the less powerful muscles working them against the softer food consumed in the earlier periods of life, would not be strong enough for the fully developed jaws and muscles, and the harder food, of the adult. Hence, they are removed to make way for a larger set, which also, when once formed, undergo no change in size. Their formation and classification commence, indeed, at very early periods of life, the ossification of the first permanent teeth beginning at the age of six months, and that of the last molars, or wisdom teeth, at about twelve years of age; yet their size is proportionate to the dimensions of the future alveoli and jaws, and to the future wants of the still undeveloped adult. The formation of the permanent teeth presents one of the clearest examples of anticipative design in the animal economy; for they are laid down, and their crowns even are fully formed, whilst the jaw itself is still too small for their proper accommodation, and their future alveoli do not even exist.

The eruption of the permanent teeth corresponds, generally, with that of the milk set. Thus, the permanent incisors succeed to the temporary incisors, the canines of the one set, to those of the other, and the two permanent bicuspids, to the two temporary molars. The three permanent molars on each side are cut, like the milk teeth, directly through the gums.

The cutting of the milk teeth, is doubtless, in many cases, though not necessarily, a painful process; it may even produce reflex nervous irritation, which may affect the digestive, circulatory, or muscular systems, causing diarrhœa, fever, convulsions, or paralysis. Lancing the

Fig. 86.

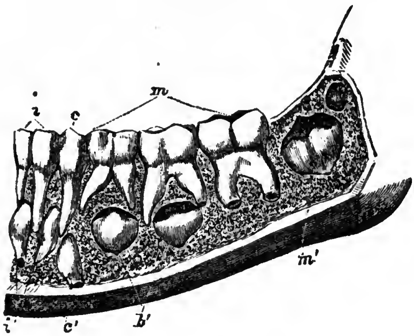
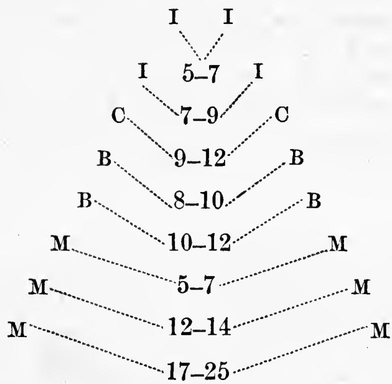


Fig. 86. Left side of lower jaw, at the age of five years, having the bony substance partly removed, to show the second set of teeth, forming beneath the temporary or milk teeth. *i*, temporary incisors. *c*, temporary canine. *m*, first and second milk molar, and first permanent molar. *i'*, permanent incisors, forming in recesses or sacs within the jaw, below the milk incisors. *c'*, permanent canine. *b'*, permanent bicuspids, commencing below the two milk molars, which they replace. *m'*, second permanent molar, rising behind the first, which is already through the gum. Above and behind this, is the sac of the wisdom tooth, or third permanent molar.

gums of children, affords relief in two ways: it removes the tension of the inflamed gums, and also leads to the formation of a yielding and easily absorbed cicatrix, in place of the firmer tissue of the gums. The cutting of the ten anterior permanent teeth, is unattended by pain, for the crown of each, passes through an opening in the gum, left by the shedding of a milk tooth; but the cutting of the permanent molar teeth, which have no precursory temporary teeth, is usually a painful process, more particularly the cutting of the wisdom teeth, the jaw and gums being frequently so cramped, that the tooth has not sufficient room to rise.

At about the age of five years, immediately before the shedding of any of the milk teeth, the jaw-bone contains more teeth than at any other period of life; for, besides the milk teeth, all the permanent ones, except the wisdom teeth, are found in an advanced stage of growth embedded in the bone (see Fig. 86, and description). The rudiments of the wisdom teeth first appear about the sixth year. The order and date of the eruption of the permanent teeth, in the lower jaw, are expressed in *years*, in the annexed diagram; the corresponding teeth in the upper jaw appear usually, in each case, somewhat later.



In accordance with the increased number and size of the permanent teeth, contemporaneous alterations take place in both jaws. In youth, the alveolar border is almost semicircular, but in the adult, semi-elliptical; it is, of course, shallow in the child, and deeper and broader in the adult; its hinder part especially, enlarges for the accommodation of the permanent molars. At first, the wisdom teeth of the upper jaw, lie behind and above the second molars; in the lower jaw, these teeth are embedded in the base of the coronoid processes, but descend to their proper position, as the jaw elongates. In the infant, the angle formed behind by the lower jaw is very obtuse; in the adult, it is nearly a right angle; but in old age, when the teeth have fallen out, it again becomes more obtuse. The obtuseness of this angle favors the approximation of the edges of the jaws in the absence of teeth, both in infancy and old age.

The *use* of the incisor teeth is to seize and divide, like scissors, the softer portions of the food. The pointed canine teeth, stronger, and situated at the sides of the dental arches, also cut or pierce the food; whilst the bicuspids, and especially the molars, or grinders, are employed in bruising, crushing, triturating, and grinding it. The harder parts of our food are broken by the lateral, or posterior teeth only. To accomplish these purposes, the lower jaw is made movable upon the upper one, which has no movement, except in conjunction with the skull itself. By two projections placed at the summit of its back part, named condyles, the lower jaw articulates with the hinder part of two depressions in the temporal bones, named the *glenoid fossæ.* The condyles of the lower jaw are flattened before and behind, and widened transversely; their long diameters are, however, not quite transverse, but are inclined backwards and inwards, so that lines passing through them, would meet at a point further back in the skull. Each condyle has a loose hinge and gliding movement, in the corresponding glenoid fossa; but the two together form a firm hinge-joint, admitting also of movements, in which both condyles glide a little forwards and backwards, out of and into the fossæ. Moreover, when this motion is limited to one condyle, the lower jaw and teeth move sideways under the upper ones, to the right hand or to the left, the point of the chin being carried in the same direction. For the better adaptation of the articular surfaces, and the greater security of the joint, a biconcave *interarticular cartilage*, thin or perforated at its centre, and thicker at its margins, is interposed between the condyle and the glenoid fossa, and is carried with the condyle, in all the movements of the jaw, especially in the backward and forward movements, in the lateral movements, and in extreme depression of the jaw, as in yawning. This latter motion is checked by the pterygo-maxillary ligament. Owing to the slight sliding movement of the cartilage, the axis of motion of the lower jaw is not at the joint, but a little below it, in a line with the grinding surfaces of the teeth.

The force employed in moving the lower upon the upper jaw is muscular, and the agents immediately concerned are the *muscles of mastication*. In opening the mouth, the lower jaw partly descends by its own weight; but it is also drawn downwards by that portion of the digastric muscle which ascends from the sides of the hyoid bone, and is inserted into the hinder surface of the front part of the lower jaw. The platysma myoides, a muscle of the neck, may also assist in drawing the jaw down, and so likewise do the genio-hyoid and mylo-hyoid muscles, which ascend to it from the hyoid bone, this bone being fixed by the sterno-hyoid and omo-hyoid muscles, which ascend to it from the sternum and the scapulæ, and also by the stylo-hyoids and the hinder portion of the digastrics, which descend to it from the styloid processes, and the inner part of the mastoid processes of the temporal bone. The external pterygoid muscles also draw the jaw forwards, and so aid in its opening.

The closure of the jaw is accomplished by muscular effort only, the muscles concerned being the most powerful of those of the head and face. The chief of these are the *temporal* muscles, which descend from the temporal fossæ at the sides of the skull; each arises from the frontal, parietal, temporal, and sphenoid bones, passes beneath the zygomatic arch, and is attached to the so-called coronoid process, at the upper and anterior end of the ascending part of the lower jaw, about an inch and a half in front of the condyle or joint. The leverage with which these muscles act, is greater than if they had been attached nearer to the condyles; their action is like that of a lever of the third order, in which strength is, to a certain extent, sacrificed to rapidity of motion. Another muscle of mastication, on each side, is the *masseter*, a very thick and powerful muscle, which descends from the lower border of the zygomatic arch and neighboring part of the malar bone, and is inserted into the outer surface of the lower jaw, near its angle, both on its ascending and horizontal part. Each of these muscles consists of a superficial part, the fibres of which are directed downwards and backwards, and of a deep part, the fibres of which descend obliquely forwards; whilst, therefore, the whole muscle closes the jaw, the superficial part can draw this bone a little forwards, and the deeper part, slightly backwards. On the inner side of each ascending portion of the jaw, between it and the cavities of the mouth and pharynx, are two other strong muscles, named the *external* and *internal pterygoids*, which proceed from the so-called pterygoid processes of the sphenoid bones, and from the palate bones, and pass, the external one horizontally backwards and outwards, to the inner surface of the neck of the condyle of the lower jaw, and the internal one, obliquely backwards and downwards, to the inner surface of the ascending part and angle of the jaw. The latter muscles, on each side, cooperate with the temporals and masseters, in raising the jaw, and assist a little in drawing the bone forwards; but the external pterygoids are the muscles chiefly concerned in executing this latter movement, as in protruding the chin. The backward movement is accomplished by aid of the posterior fibres of the temporal, and by the internal pterygoids. The external pterygoid of one side, causes the lateral motion of the bone upon its opposite condyle, and the lateral movement of the chin over to the other side. To accomplish the forward gliding movement of the interarticular cartilage, and, at the same time, to withdraw the two synovial membranes, situated above and below it, from the risk of pressure, certain fibres of the external pterygoid muscle are fixed to the anterior edge of the interarticular cartilage, and also to both synovial membranes. The movements of the masticatory muscles accelerate the flow of saliva and mucus into the mouth.

The chief movement, employed in dividing or lacerating soft food, is a direct ascent of the lower jaw, accomplished by the temporal, masseter, and internal pterygoid muscles. In crushing harder food, or in the bad practice of cracking nuts with the teeth, the same movement occurs, the substance being placed far back between the molar teeth, not only because these teeth are broader and stronger than the rest, but because the muscular force is used with greater effect, the nearer to the fulcrum it is exerted. The advantage of having the molar teeth in the part of the jaw nearest to the fulcrum is obvious. A simple upward movement of the lower jaw is insufficient for the purposes of mastication; but the necessary bruising and trituration of the food, are accomplished by its backward and forward movements, and especially by the lateral movement, combined with a slight backward and forward action, which cause a rotatory or grinding motion of the lower teeth upon the upper ones.

Mastication is extremely important in the case of all solid, firm, or fibrous food, as well as of that which is hard and dry, preparing it, by comminution for the action of the digestive fluids; when it is hurriedly or imperfectly performed, dyspepsia often ensues.

In the act of mastication, the saliva plays an important *mechanical* part, as, indeed, it also does in the movements of the tongue in speech. Poured into the mouth at various points, especially from the inner side of the cheeks near the molar teeth, it not only lubricates the mucous membrane, thus facilitating the requisite and constant motion of the food in the mouth, and moistens the teeth, so as to prevent the adhesion of the food by the clogging of their grinding surfaces, but, mixed with the food, it materially assists in softening it, and converting it into a pulpy mass, fit to pass down through the membranous gullet. In mastication, the food is also mixed with a small quantity of air. It has been observed that in the mastication of dry food, such as crusts or biscuits, a larger quantity of saliva is, for a time, secreted than in the case of softer food; this is probably, in part at least, due to the more vigorous action of the muscles of mastication, exciting a general determination of vascular and nervous energy to the parts. It was found by Bernard, in experiments made by opening the œsophagus of a horse, that the mass of food swallowed, was usually mixed with about ten times its weight of saliva; when the Whartonian ducts were tied, mastication was performed much more slowly, and the food mass, taken from the œsophagus, was drier, though covered with mucus, and weighed only three and a half times its original weight.

Certain movements, which co-operate in mastication, are performed, within the dental arches, by the tongue, and on the outer side of these arches, by the *buccinators*, or *cheek muscles*, which compress the cheeks. These movements serve to place, and hold, the food between the teeth, to turn it, so that fresh portions may be subjected to the pressure of the teeth, and, finally, when it is fully masticated, to push or withdraw it from between the teeth, so that it may be swallowed. The tongue also aids in crushing soft masses of food, and forming them into suitable boluses to pass into the pharynx and gullet.

The *tongue* is a muscular organ, composed of two symmetrical halves, separated from each other by a median fibrous septum, and covered by mucous membrane and a submucous fibrous stratum. The muscles of this organ are *extrinsic* and *intrinsic*. The *former* pass into the tongue at its base and under surface, and connect it with neighboring parts; they are four in number in each half of the tongue, viz., the *hyo-glossus*, the *genio-hyo-glossus*, the *stylo-glossus*, and the *palato-glossus*, so named from their respective bony attachments. A few fibres of the superior constrictor muscle of the pharynx are also connected with the side of the tongue. The *intrinsic*, or proper muscles of the tongue, are the *superior longitudinal*, the *inferior longitudinal* or *lingualis*, and the *transverse*.

The *hyo-glossus* is a thin quadrilateral muscle, which, arising from the hyoid bone, passes upwards to the side of the tongue, to be inserted between the stylo-glossus and the lingualis. Beneath the hyo-glossus is a flat triangular muscle, the *genio-hyo-glossus*, the apex of which arises from the inner surface of the anterior portion of the lower jaw, its base being inserted into the hyoid bone, a small portion of the pharynx, and the entire length of the under surface of the tongue. The *stylo-glossus* arises from the styloid process of the temporal bone, and divides into two portions on the side of the tongue, one longitudinal, blending with the lingualis, the other oblique, decussating with the hyo-glossus. The *palato-glossus*, which, as previously mentioned, forms, on each side, the anterior pillar of the soft palate, passes from the soft palate to the side and upper surface of the tongue, where it joins the fibres of the stylo-glossus.

Of the intrinsic muscles, the *superior longitudinal* muscle occupies the upper surface of the tongue, close beneath the mucous membrane, extending from its apex to the hyoid bone; some of the fibres are longitudinal, others oblique; many of them are branched or undergo subdivision, and are connected, at intervals, with the submucous and glandular structures. The *inferior longitudinal*, or *lingualis*, muscle reaches from the apex to the base of the tongue, lying between the hyo-glossus and the genio-hyo-glossus, blending anteriorly with the fibres of the stylo glossus. Between the superior longitudinal and the lingualis are placed the transverse fibres; internally, these are connected with the median fibrous septum, and, passing outwards, they are inserted into the dorsum and margins of the tongue, where they intersect the other muscular fibres. These transverse fibres form the greater portion of the substance of the organ; they are intermixed with a considerable quantity of fat.

From the varied course of its component fibres, the tongue possesses the power of movement in all directions.

For the act of sucking, the tongue is especially important. The lips of the infant being closely applied to the breast, the tongue is drawn back, and the threatened vacuum in the mouth is filled with milk, forced in by the atmospheric pressure on the breast, as well as by the elasticity of the distended ducts of that organ. By means of the palate, uvula, and posterior pillars of the fauces, the respiratory passages through the nose and pharynx are shut off, so that air cannot enter the mouth by that path, and, moreover, respiration is not hindered until the act of swallowing takes place. Drinking, with the lips closed on the rim of any vessel, involves a similar mechanism; but the fluid is often allowed to enter the mouth by its gravity only. In sipping, the fluid is drawn in by an inspiratory movement; and, most commonly, the act of drinking is performed partly by sipping, and partly by pouring the fluid into the mouth. In drinking from a stream, the lips are protruded and submerged, and a combination of sucking with oral inspiration, takes place.

Deglutition.

Deglutition, or the act of *swallowing*, is that mechanical process by which the food is passed from the mouth, through the opening called the *fauces*, into the *pharynx*, and thence along the *gullet*, into the stomach. This act is usually described as consisting of three stages: first, that in which the food is forced backwards from the mouth, through the fauces, into the pharynx; secondly, that in which it is made to traverse the middle and lower part of the pharynx to the gullet; and thirdly, that in which it descends along the gullet, and enters the stomach.

The *first stage* of deglutition is performed by aid of the *tongue*, the hinder part of the *hard palate* and the *soft palate*, together with the so-called *pillars of the fauces*. The hard palate is formed by parts of the superior maxillary and palate bones, covered by periosteum and a dense mucous membrane. The soft palate descends, like an apron, from the posterior border of the hard palate, and forms the upper margin and sides of the opening, seen on looking into the mouth, called the fauces. The arched border of this opening, forming the *isthmus of the fauces*, presents, in the middle line above, the pendulous body, named the *uvula*. Two prominent ridges, on each side, are called the *pillars* of the fauces; the *anterior pillars* pass down on the sides of the tongue, the *posterior pillars*, on the sides of the pharynx; between the two pillars, on each side, is a depression, in which are lodged the soft, projecting, oval, or almond-shaped, somewhat rugose, glandular bodies, named the *amygdalæ* (almonds), or *tonsils*. These bodies present a number of follicular depressions, the sides of which are surrounded by small closed spherical sacs, analogous to those of the so-called Peyer's patches in the intestines; they have thickish walls, lined by an epithelium, and contain a tenacious grayish-white secretion; sometimes they open on the surface.

The mucous membrane of the under surface of the soft palate is covered with a squamous epithelium, and possesses numerous compound racemose mucous glands. The mucous membrane of the upper surface, turned towards the superior part of the pharynx, is continuous with that of the nasal fossæ, and, near the openings of the Eustachian tubes, has a ciliated columnar epithelium. Between the two layers of mucous membrane, which join at the free border of the soft palate, are found, besides areolar tissue, bloodvessels, lymphatics, and nerves, a number of symmetrical muscles, by means of which the soft, pendent, valve-like palate, is rapidly moved in various directions. Thus, the palate and uvula are raised by the *levator palati*, a thin sheet of muscular substance, which descends from the petrous part of the temporal bone, and from the Eustachian tube, to the back of the soft palate; moreover, two small auxiliary muscles descend within the uvula, constituting together the so-called *azygos uvulæ* muscle, which elevates the uvula. Descending from the pterygoid processes of the sphenoid bone, and from the Eustachian tube, on each side, is a muscle, terminating below in a little tendon, which turns beneath the *hamular*, or hooked-like end of the pterygoid process, and so, changing its direction, spreads out towards the middle line within the soft palate, and unites with its fellow of the opposite side. This muscle, acting from its point of reflection over the hamular process, tightens and spreads out the soft palate, hence its name, *circumflexus*, or *tensor palati*. The two pillars of the fauces, on each side, likewise contain small muscles; those within the anterior pillars are named, from descending to the tongue, the *palato-glossi* muscles; and those within the posterior pillars, from passing to the sides of the pharynx, the *palato-pharyngei* muscles. These muscles draw the soft palate downwards, and either backwards or forwards, in the direction of the tongue or palate; by their joint action on the two sides, they also contract the aperture of the fauces to a triangular fissure, which can then be completely closed by the uvula. By the variously combined actions of the surrounding muscles, the fauces can be closed, whether the palate be drawn upwards or downwards. By the approximation of the posterior pillars to the uvula, and by the simultaneous elevation of the palate, the middle part of the pharynx can be shut off from its upper part, so that this latter, or the respiratory, portion, which communicates with the nasal fossæ, is separated from the middle part, through which the food has to descend.

In the first stage of deglutition, the lower jaw is raised, the mouth is closed, and its cavity made smaller; the mass of food, sufficiently masticated, and softened by the saliva, is placed between the tongue and the hard palate, and is then pressed backwards, by a movement of the tongue, beneath the slightly sloping soft palate, which is rendered tense by the circumflex muscles. The anterior pillars of the fauces are separated, to receive the mass, whilst the posterior pillars and the uvula, by being elevated and approximated in the manner just described, shut off the upper part of the pharynx and the posterior nasal openings. The tongue, becoming shorter and thicker, its posterior part is rendered convex, and, by means of the mylo-hyoid muscles, which form the muscular floor of the mouth, and also by the digastricus, stylo-hyoids, and thyro-hyoids, is then forced upwards and backwards, and following the mass of food, propels it, through the fauces, into the middle portion of the pharynx; thus is completed the first stage in the act of deglutition.

The *second stage* of deglutition is performed through, and by, the *pharynx.* This is a musculo-membranous sac, or bag, about 4½ inches in length, and wider above than below, which is suspended from the base of the skull, in front of the vertebral column, and behind the cavities of the nose, mouth, and larynx, with all of which it communicates. It is through the larynx, that the air passes to and from the lungs. On a level with the lower border of the larynx, the pharynx becomes continuous with the œsophagus, or gullet. The pharynx, Fig. 87, has seven openings leading into it. At its upper part, in front, are the two posterior nares, *n*, or nasal openings; at each side, are the

Fig. 87.

Fig. 87. Back view of the pharynx and part of the œsophagus, suspended from the base of the skull, and laid open behind. *n*, openings of the nasal cavities, called the posterior nares, separated by a median septum. *p*, soft palate, with the uvula depending from it, in the centre. Below this, the arches of the fauces, bounded by its posterior pillars: beneath this arch, is seen the back of the tongue. *e*, the epiglottis, or valve which protects the superior aperture of the larynx. *l*, the back of the larynx, seen in the opened part of the œsophagus. *o*, the œsophagus. *t*, the trachea, or windpipe.

apertures of the Eustachian tubes, which lead to the tympanic cavities of the ears; these four openings are above the level of the soft palate. Below the soft palate, *p*, the pharynx opens, by the isthmus of the fauces, into the mouth; lower down, beyond the root of the tongue, is the opening, *e*, into the larynx, *l;* at its termination, is that leading into the œsophagus, *o*. The walls of the pharynx consist chiefly of three pairs of so-called *constrictor* muscles, supported by areolar tissue, and lined throughout by a mucous membrane, continuous with that of the nasal cavities, Eustachian tubes, mouth, larynx, and gullet. The constrictor muscles, named, from their relative positions, superior, middle, and inferior, overlap each other from below, that is, in the opposite direction to the slates of a roof, the inferior muscle being external to the middle one, and the middle one external to the upper one; the superior muscle, which is open in front, is, therefore, embraced, at its lower end, by the middle muscle, whilst this again is embraced by the inferior constrictor. Considered together, these constrictor muscles are attached, above, to the base of the skull; in front and at the sides, to various parts of the bones of the skull and face, and also to a fibrous band passing from the styloid process of the temporal bone to the lower jaw; still lower down, to the side of the tongue, to the stylo-hyoid ligament, and the hyoid bone; and, lastly, to the thyroid and cricoid cartilages of the larynx. Posteriorly, the fibres of the constrictor muscles, sweeping backwards in a curved direction, meet at a raphé, or median line, along the back of the pharynx. Spreading out on each side of the pharynx is the stylo-pharyngeus muscle, which descends from the styloid process, and also the *palato-pharyngeus*, which passes down in the posterior pillar of the fauces. The upper portion of the pharynx, above the level of the soft palate, is exclusively respiratory, and its mucous membrane is covered with a columnar ciliated epithelium; the middle portion, through which not only air, but food and drink pass, and the lower portion below the laryngeal aperture, which is devoted exclusively to the passage of food and drink, are covered with a squamous non-ciliated epithelium. Numerous simple and compound racemose mucous glands open upon the pharyngeal mucous membrane, and moisten it with their secretion.

In the *second stage* of deglutition, the softened mass of food, forced, by the backward movement of the tongue, into the middle portion of the pharynx, is compressed, in rapid succession, from above downwards, by the lower fibres of the superior constrictors, and more especially by those of the middle and inferior constrictors, and thus is propelled *rapidly* into the upper end of the gullet. At the same time, the upper fibres of the superior constrictors, and especially the fibres of the stylo-pharyngei muscles, draw upwards, and somewhat outwards, the pharyngeal walls over the mass of food, as this is forced downwards. The superposition of the constrictors, one upon the other, from above downwards, facilitates the propulsion of the food in that direction; moreover, the food itself meets with no obstruction from the edges of the two lower constrictors, as would have been the case, had the imbrication of the muscles been in the opposite direction. The second stage of deglutition is rapidly performed, because respiration is suspended during its occurrence. Provision must also be made, during this stage of deglutition, for the safe transit of drink and food through the pharynx into the gullet, without any drop or particle being forced upwards into the nasal fossæ, where it would excite irritation, or downwards into the larynx, whence it would descend into the windpipe, and cause coughing, difficulty of breathing, or suffocation. The posterior nares are accordingly protected by the elevation and tension of the soft palate above the middle portion of the pharynx, in the mode already described (p. 502), so as to form an inclined plane, beneath which the food glides into the pharynx, as this ascends to receive it. At the same time, the opening into the larynx is protected by the epiglottis, a leaf-like valve, situated at the root of the tongue (p. 200), Fig. 87, *e*, Fig. 9, *e*. This valve, in the ordinary condition of the parts, stands erect, with its free margin directed upwards; the larynx then communicates with the middle portion of the pharynx, and air can pass from the nose, and mouth, if that be open, to and from the windpipe and lungs. When, however, the tongue is raised, and pressed backwards at the end of the first stage of deglutition, the larynx is elevated, and the mass of food, or the portion of liquid, then swallowed, presses the previously erect epiglottis downwards and backwards, so as, together with certain folds of the mucous membrane connected with its borders, completely to close the opening into the larynx, whilst the food or drink is passing by it, into the lower portion of the pharynx. The moment the solid or fluid has thus passed down, the tongue resumes its previous position, the epiglottis is again erected by the elastic folds connecting it with the anterior part of the larynx and root of the tongue, and the air-passage is once more free for the purposes of respiration.

The *third stage* of deglutition is performed by aid of the muscular walls of the *gullet* or *œsophagus*. This musculo-membranous tube is that portion of the alimentary canal, which extends from the pharynx down to the stomach. It measures about nine inches in length, and is the narrowest part of the alimentary canal, being itself narrowed at its lower, but narrowest at its upper end. It descends through the lower part of the neck and through the whole length of the thorax, and then, perforating the diaphragm, opposite the ninth dorsal vertebra, enters the abdominal cavity, and immediately opens into the stomach. It is supported upon the vertebral column, being placed between the carotid arteries, and behind the trachea, the heart, and the arch of the aorta; below the latter, it lies in the space between the two pleuræ, to the right; and then in front, of the descending aorta; it traverses the diaphragm through a special opening, named the œsophageal opening. The walls of the œsophagus are composed of three coats, muscular, areolar, and mucous.

The *muscular* coat consists of an external layer of *longitudinal fibres*, and an internal layer of *circular fibres;* at the upper end of the œsophagus, these fibres are chiefly striated, and striated fibres are to be found in smaller numbers even down to its lower end; but the great mass of the muscular coat consists of the plain, or unstriped, muscular fibres. The areolar coat is a soft distensible tunic, which supports the mucous coat. The mucous coat, reddish above, and pale below, is thick, and when the œsophagus is closed, it is thrown into numerous longitudinal plicæ; in this state, a section across the tube presents no cavity, but, in its centre, a radiating or branching cleft, formed by the meeting of the plicated folds. The pharynx is permanently open, as far as the aperture leading into the larynx, but its lower portion, and the whole length of the œsophagus, are habitually closed, their sides being always in contact, excepting when solids, fluids, or gases are passing through them; they are examples of what are called *potential cavities*. When, however, any solid or fluid is passing down the œsophagus, the longitudinal plicæ of its mucous coat are obliterated. This membrane is beset with papillæ, and covered with a many-layered squamous epithelium, which, at the lower end of the œsophagus, at the line of junction with the stomach, abruptly changes its character, and presents a crenulated border. The mucous membrane of the œsophagus is provided, especially at its upper and lower ends, with small compound mucous glands.

In the third and final stage of deglutition, the food, pressed down by the muscles of the pharynx, first distends the walls of the œsophagus, the muscular coat of which, however, speedily contracts above the morsel, and so urges it further downwards; the part thus dilated, then contracts above the mass of food, which is thus driven on, and so, by a succession of similar acts, is propelled, in separate portions, into the stomach. This successive contraction of the muscular coat of the œsophagus, from above downwards, is called *vermicular* or *peristaltic*. The circular fibres contract, in a wave-like manner, from above downwards, and are the propulsive agents; whilst the longitudinal fibres, drawing up and widening the walls of the œsophagus, over the sides of the morsel of food, facilitate its descent. Gravitation, though it may assist, has but little influence on the downward movement of food or liquids. The resistance to be overcome is slight, consisting only of the elastic pressure of the walls of the œsophagus and of the surrounding parts. Solid substances, and even fluids, are habitually swallowed by the horse and other animals, against the force of gravity; and certain clowns can perform the feat of eating and even drinking, whilst "standing upon their heads." The rate of motion of food through the œsophagus, is not so rapid as that through the pharynx. Ordinarily, the movement causes only a slight sensation at the upper end of the œsophagus; but if the morsel be too large, the act is painful, especially as the mass is passing through the diaphragmatic œsophageal opening. As the œsophagus receives fibres coming from the spinal accessory nerves, but reaching it through the pneumogastrics, division of the latter in the neck paralyzes the lower part of this tube, so that the food remains in it, and distends it. It also receives sympathetic nerve-fibres.

The three stages of deglutition are distinguished from each other in a remarkable manner, according to the mode in which they are regulated, or governed, through the nervous centre. The *first* stage is *voluntary;* we place the food between the tongue and the palate, and, by an effort of the will, pass it backwards through the fauces, into the pharynx. Even the accompanying movement of the soft palate, to shut off the nasal fossæ, which is an associated movement, so determined by habit as to be unconsciously performed, is nevertheless a voluntary movement, or at least one which, by trifling practice, may be voluntarily performed. The *second* stage is, however, wholly *involuntary* and *automatic*, and is performed through the intervention of a reflex action, though it may be partly imitated by the will. No sooner has the food reached a certain part of the fauces, than it excites afferent nerves distributed to that part, the impressions on the fibres of which, being conveyed to a certain nervous centre, are reflected through efferent fibres of other nerves, to the various and numerous muscles required to contract; and, by the simultaneous action of these, this stage of deglutition is rapidly performed. Whilst, then, the first stage, which involves no obstacle to respiration through the nose and pharynx, is voluntary and deliberate, the second stage, during which respiration must be suspended, is involuntary and rapid, and, moreover, is not intrusted to movements requiring practice, habit, or attention, to insure their perfect co-operation, but is performed as promptly, efficiently, and safely, the first time by the new-born infant, as at any after period of life. The accidental passage of food or drink into the air-passages, with its accompanying inconveniences, incidentally proves the advantage of the perfect performance of this movement. The afferent nerves concerned in this important reflex act, are those supplying the mucous membrane of the fauces and neighboring parts of the pharynx, viz., the palatal branches of the fifth pair, and, chiefly, the pharyngeal branches of the glosso-pharyngeal and pneumogastric nerves; the efferent or motor fibres are contained, some in the former, but mostly in the latter nerves, being, however, derived partly from the spinal accessory nerves (p. 267). Some also belong to the hypoglossal, which governs the movements of the tongue, and certain muscles of the neck; to the facial nerve, which supplies the digastric and stylo-hyoid muscles; and perhaps a few to the cervical spinal nerves. The reflex nervous centre is situated in the medulla oblongata, and upper part of the spinal cord. The *third* stage of deglutition is also entirely *involuntary*, and chiefly, if not wholly, *reflex*. The afferent fibres concerned, are contained in the œsophageal branches of the pneumogastric nerves, and the efferent fibres are included in the same branches, derived partly, however, from the spinal accessory nerves. It is supposed by many, that the non-striated muscular fibres of the œsophagus, may be *directly* stimulated by the substances swallowed, without the intervention of any reflex nervous action.

Movements of the Stomach.

The *stomach*, Figs. 13, 89, *s*, the dilated part of the alimentary canal, into which the œsophagus opens above, and from which the small intestine leads below, is a musculo-membranous bag, of a peculiar shape, extending across the abdominal cavity, from left to right, in front of the vertebral column, just below the diaphragm and liver, immediately behind the anterior wall of the abdomen, and above the transverse colon. It is somewhat pear-shaped, the wider end, *fundus* or *cardiac* end, Fig. 89, *o*, being turned to the left side, and the smaller or *pyloric* end, *p*, which ends in the small intestine, being turned to the right side. The œsophagus enters the stomach a little to the right of the cardiac end. The upper border of the stomach is concave, and is named the *lesser curvature;* the lower border, convex, is called the *greater curvature;* the left end of the stomach, beyond the entrance of the œsophagus, is named the *great cul-de-sac,* and a slightly dilated part of the convex border, towards the left end of the stomach, is called the *lesser cul-de-sac.* After death, the human stomach sometimes has an hour-glass form, being constricted across its middle, or somewhat nearer its pyloric end. The stomach has two apertures, one named the *œsophageal* or *cardiac* opening; and the other the *pyloric* opening. It is attached, by its œsophageal end, to the diaphragm, and by its pyloric end, to the back of the abdomen; the lesser curvature is attached, by a double fold of the peritoneum, or lining membrane of the abdomen, to the under surface of the liver; the left end, or great cul-de-sac, of the stomach, is connected, by a similar fold, with the spleen, and the greater curvature is loosely attached, by like folds, to the transverse colon. The greater curvature is the most movable part of the organ, which, when empty, is flattened on its anterior and posterior surfaces; but, as its cavity is filled, it is tilted forwards and upwards, so that its anterior and posterior surfaces are then turned, respectively, obliquely upwards and forwards, and downwards and backwards, the œsophageal and pyloric ends remaining almost stationary. The stomach descends with the diaphragm during inspiration, and ascends in expiration; its state of distension affects the cavity of the chest, and, when over-distended, causes dyspnœa and palpitation of the heart.

The capacity of the stomach is most variable, ranging from complete emptiness, with its walls in contact with each other, to a condition of full distension, in which it may hold three pints. When moderately full, it measures 12 inches in length, by 4 in diameter. Its weight is about $4\frac{1}{2}$ oz.

The membranous walls of the stomach consist of four coats, viz., commencing from without, the *serous*, *muscular*, *areolar*, and *mucous* coats, all of which are held together by a more or less extensible areolar tissue. The *serous* coat, thin, transparent, and smooth, is a part of the peritoneal lining of the abdomen; the anterior and posterior surfaces of the organ are covered by distinct layers of the peritoneum, which, leaving it along its greater and lesser curvatures, become applied to each other, to form the double supporting folds named *omenta*, by which the stomach is held in connection with other parts. The serous coat is elastic, and thus accommodates itself to the variable state of distension of the organ, which is also facilitated by a loose interspace between the two peritoneal layers along its curvatures. The *muscular* coat, to which the serous coat adheres by fine areolar tissue, contains three layers of fibres, named, from their direction, longitudinal, circular, and oblique. The *longitudinal* fibres, which are next beneath the serous coat, are continuous with the longitudinal fibres of the œsophagus; they spread out over the stomach, being accumulated in great numbers along the lesser curvature, in smaller numbers along the greater curvature, and only thinly scattered upon the anterior and posterior surfaces of the organ. At the œsophageal opening, they form the so-called *stellate* fibres, and, at the pylorus, they are again disposed in a uniform layer, and become continuous with the longitudinal fibres of the small intestine. The *circular* fibres, internal to the longitudinal ones, form thin circular fasciculi at the great cul-de-sac, and surround the whole extent of the stomach up to the pyloric end, where they are collected into a dense ring, which projects inwards, and forms an annular sphincter muscle. This projecting ring, covered, on its

Fig. 88.

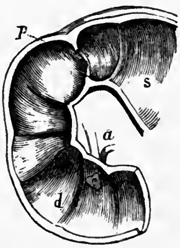


Fig. 88. Vertical section through the pyloric end of the stomach, and the curved part of the duodenum, to show the circular fold, or annular valve, at the pylorus. *s*, small part of the stomach. *d*, part of the duodenum. *p*, the pylorus, or pyloric opening of the stomach, with its annular valves. *a*, ends of the common bile duct, and the hepatic duct, entering the left side of the bend of the duodenum, to open internally by a common orifice. Much reduced in size.

interior, by the mucous membrane, constitutes the *pylorus* or *pyloric valve* (*πύλη*, *a gate*), Fig. 88, *p*, the muscular fibres of which can partially, or completely, close the pyloric aperture of the stomach. The *oblique* muscular fibres do not, like the longitudinal and circular set, to which they are internal, extend over all parts of the stomach; from around the œsophageal opening, where they are continuous with the circular fibres of the œsophagus, and form a sort of sphincter, they may be followed for a short distance on the great cul-de-sac of the stomach, spreading obliquely downwards on its anterior and posterior surfaces. The muscular fibres of the stomach are pale, and, for the most part, non-striated, though a few, in the longitudinal layer, present traces of indistinct striæ.

The *areolar* coat of the stomach, sometimes called, from its position, the *submucous* coat, consists of dense areolar tissue, containing some fatty tissue, and a delicate layer of unstriped muscular fibres. It supports the mucous coat, and, like it, is of greater extent, and less expansible, than the muscular and serous coats; with the muscular coat it is connected by very loose areolar tissue, so that in the empty condition of the stomach it is thrown, together with the mucous membrane, into numerous irregular, but chiefly longitudinal, folds, called *rugæ*. The bloodvessels, lymphatics, and nerves, belonging to the mucous coat, subdivide in the areolar coat, before they enter the mucous membrane. From the number of vessels in it, the areolar tunic was formerly named the *vascular* coat, and from its white color, the *nervous* coat; both terms, however, are objectionable. Its muscular fibres are supposed to assist, by their contraction, in the process of absorption.

The innermost, or *mucous* coat of the stomach, is a soft, pulpy, smooth membrane, of a pale straw color, after death, but of a pink, or bright red, hue during life, being much darker during digestion. It is habitually moistened with mucus. It adheres firmly to the areolar or submucous coat, and follows the folds or *rugæ* seen in the empty stomach, but which are completely obliterated when this organ is distended. The mucous membrane is provided with multitudes of glands, to be hereafter described, which secrete the gastric juice. The blood-vessels and lymphatics are numerous. The nerves of the stomach are derived, partly from the large terminal branches of the pneumogastric or vagi nerves, which are joined by the splanchnic branches of the sympathetic, and partly also by the sympathetic branches, proceeding along the arteries from the cœliac or solar plexus.

The stomach is a dilated portion, or diverticulum, of the alimentary canal, intended for the reception and retention of successive portions of fluid, and of masticated and insalivated solid food, in order that whilst the watery and dissolved parts are absorbed, the solid substances may be subjected to the action of the gastric juice. Besides these purposes, for which it is fitted by the extensibility of its serous and muscular coats, and by the loose rugæ of its less expansible submucous and mucous tunics, the stomach also, by aid of its muscular fibres, impresses peculiar movements upon the food in its interior, and urges onwards through the pylorus, into the small intestine, those portions which are sufficiently softened and digested by the gastric juice. In these movements, the longitudinal fibres shorten the stomach; the circular fibres lessen its diameter, acting peristaltically from its cardiac onwards to its pyloric end, whilst the oblique fibres draw the sides of the organ over the alimentary mass. When the stomach is empty, the several sets of fibres contract in every direction, some narrowing it, and others shortening it, and so reduce it to its smallest possible dimensions. The pyloric part diminishes relatively less than the cardiac portion. When, however, the stomach contains food, its internal surface is kept in close contact with this, and the different fasciculi of each layer acting consecutively, give rise to complicated movements in certain directions. The combined result of these, is a remarkable *rotatory*, or churning motion, which urges the food from the great cul-de-sac along the lower border of the stomach, towards the pylorus, and thence back, along the upper border to the great cul-de-sac again, and so on: such rotation is said to occupy from one to three minutes (Beaumont). In order to prevent regurgitation of the food into the œsophagus, especially during effort with the abdominal muscles, the cardiac orifice is kept closed by the circular fibres of the lower end of the œsophagus, aided by the edges of the opening in the diaphragm; the pylorus is closed by its proper muscular ring. As the outer layer of the alimentary mass becomes digested, and converted into a pulp, it is pressed by the peristaltic action of the circular fibres, through the pylorus, and escapes at intervals into the duodenum. As this pulpy portion is expelled, fresh layers of the food mass are brought into contact with the gastric walls; towards the end of digestion, larger quantities pass the pylorus. Whilst the pylorus permits the passage out of the stomach of the pulpy products of gastric digestion, such solid substances as do not yield to the digestive process are not allowed to pass, apparently because they excite the contraction of the circular pyloric muscular fibres. Such substances, as well as fish-bones, buttons, plum-stones, or other bodies accidentally swallowed, remain in the stomach for some time after the evacuation of its digestible contents; but after a certain delay, the pylorus relaxes, and allows them also to pass into the intestinal canal. The movements of the stomach are partly reflex, being excited through the pneumogastric nerves, as is shown by experiments on animals; but it would also seem probable that a direct stimulation of its muscular fibres may co-operate. The sphincter fibres at the cardiac end appear to be under the government of the sympathetic nerves. It is not known whether the contraction of the pylorus is a reflex act.

The gastric movements aid in the function of digestion, by rotating the food in the stomach, thus exposing all parts of the digesting mass to the action of the gastric fluid, and by continually removing the softer parts from the surface, and expelling them gradually through the pylorus, so that fresh portions of that surface are then exposed. The pressure exercised upon the contents of the stomach, may further assist in the process of venous absorption. It is to be observed, however, that portions of food, placed in perforated metal tubes or balls, and introduced into the stomach, are nevertheless digested.

Movements of the Intestines.

The *intestinal canal*, Fig. 89, *d* to *r*, or portion of the alimentary canal extending from the stomach downwards, is divided into a longer and narrower part, called the *small intestine*, *d* to *i*, and a wider and shorter part, named the *large intestine*, *c* to *r*.

The *small intestine* extends from the pylorus, *p*, to a valvular opening leading into the large intestine, *c*; it measures about 20 feet in length, and becomes somewhat, though slightly, narrower from above downwards. This long tube lies in *coils*, or *convolutions*, occupying the middle and lower part of the abdominal cavity, and the pelvis, Fig. 13. It is supported by a broad double fold of the peritoneum, named the *mesentery*, which is attached, by a shorter posterior margin, to the back of the abdomen, but is connected by a longer anterior margin, with the back of the small intestine, so that both it and the intestine are thrown into folds, which are capable of constant change in form and position. The layers of the mesentery are prolonged over the intestine, and form its outer or serous coat; and between these two layers, are contained the bloodvessels, lymphatics, and lymphatic glands, and the nerves of the intestine, all of which help to support this part.

The small intestine commences on the right side of the vertebral column, beneath the right lobe of the liver, and after undergoing its numerous convolutions, terminates in the lower part of the right side of the abdomen. For purposes of description, it is said to be composed of three portions: first, of a short portion named the *duodenum*, *d, d* (*duodeni*, twelve), because it corresponds in length to the width

Fig. 89.

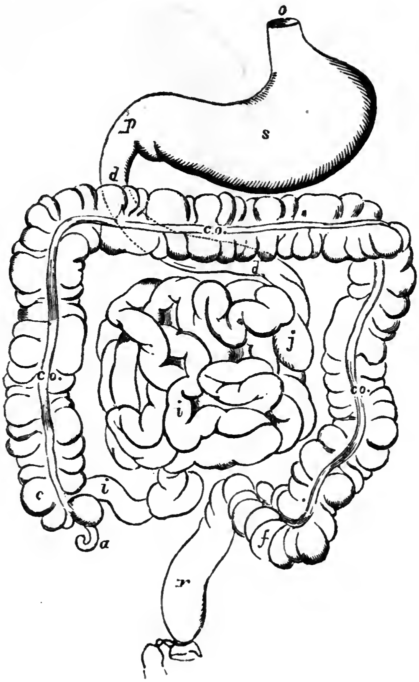


Fig. 89. Diagram, showing the abdominal portion of the alimentary canal, its subdivisions, and the general position of these in the abdomen. *s*, the stomach. *o*, the œsophageal, or cardiac end. *p*, the pylorus. *d, d*, the duodenum, or first portion of the small intestine, curving from right to left. *j*, coils of the jejunum, or second part of the small intestine. *i, i*, coils of the ileum, or third and last part of the small intestine. *c*, the cæcum, or first part of the large intestine, with its vermiform appendix. *co. co, co*, ascending, transverse, and descending portions of the colon. *f*, sigmoid flexure of the colon. *r*, straight intestine or rectum. The small intestine is seen to occupy the middle of the abdomen, and to be surrounded on three sides by the large intestine.

of twelve fingers placed side by side; secondly, of a longer portion named the *jejunum*, *j* (*jejunus*, fasting), from its being usually found empty after death; and, lastly, of a still longer portion, named, from its numerous coils or convolutions, the *ileum*, *i* (εἴλειν, to coil).

The *duodenum*, *d, d*, is about 8 or 10 inches long; it is the widest part of the small intestine, measuring from 1½ to 1¾ inches in diameter; it is also the most fixed part, having no mesentery, the peritoneum merely covering it in front, except near the stomach. The duodenum describes a horseshoe-like curve, the convexity of which is turned to the right; first it ascends, for about 2 inches, towards the under surface of the liver and gall-bladder; then it descends in front of the right kidney; next it passes from right to left, across the second lumbar vertebra, the attachment of the diaphragm, the ascending vena cava, and the aorta, and passing slightly upwards, joins the jejunum, opposite a line corresponding with the superior mesenteric artery and vein. In the concavity of the curve of the duodenum, is placed the

Fig. 90.

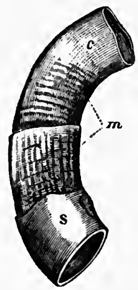


Fig. 90. Portion of the small intestine, dissected, to show the position of its several coats. *s*, the outer, smooth, serous, or peritoneal coat. *m*, the muscular coat, composed of an outer layer of longitudinal fibres, and an inner layer of circular fibres. *c*, the submucous and mucous coats united together. Much reduced in size.

right end or head of the pancreas, which is here attached to the intestine. The common bile duct and the pancreatic duct, open into the duodenum.

The *jejunum*, *j*, forms about two-fifths, and the *ileum*, *i*, *i*, the remaining three-fifths of the part of the small intestine below the duodenum. The jejunum occupies the middle and left regions of the abdomen; whilst the ileum is placed in the middle, lower, and right regions, and, occasionally, partly descends into the pelvis. The termination of the ileum in the large intestine, *c*, is situated in the right iliac fossa. The jejunum has thicker and dark-colored coats, and is somewhat wider than the ileum, the average diameter of the former being $1\frac{1}{4}$ inch, that of the latter 1 inch.

Fig. 91.

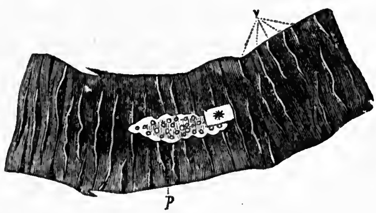


Fig. 91. Portion of the small intestine, laid open to show the smooth internal coat or mucous membrane, which is here thrown into numerous transverse double folds or ridges, which are permanent. These are the valvulæ conniventes, *v*. A patch of the so called Peyer's glands, or glandulæ agminatæ, or aggregatæ, with its little component round sacs, is shown at *p*. The oblong white piece of card, partly covering the patch of Peyer, and marked with an asterisk, *, shows the relative size of the piece of mucous membrane represented in Fig. 98.

The membranous walls of the small intestine are composed, like those of the stomach, of four coats; viz., the serous, muscular, areolar, and mucous coats. The *serous* coat, Fig. 90, *s*, derived from the peritoneum, is thin and elastic, to permit of various degrees of distension; whilst the smoothness and moisture of its free surface, facilitate the changes of form and position of the intestinal convolutions upon each other, and upon adjacent parts. The *muscular* coat, *m*, consists, as elsewhere, of an external layer of longitudinal, and an internal layer of circular fibres. The longitudinal layer is thinner than the circular layer, and is most distinct along the free border of the intestine; the circular fibres are arranged more closely together. The *areolar* or *submucous* coat, *c*, is loosely connected with the muscular coat, but more firmly with the mucous membrane, which it supports. Thin crescentic extensions of this areolar coat project transversely, at intervals, into the interior of nearly every part of the small intestine, and, covered, on both sides and at their edges, by the closely adherent mucous membrane, constitute the so-called *valvulæ conniventes*, Fig. 91, *v*. These valves may be displayed by opening the intestine, and immersing it in water. In a portion of intestine inflated, dried, and laid open longitudinally, they are seen as transverse crescentic folds or ridges, wider in the middle, and tapering at either end. Each extends about half or two-thirds around the interior of the tube; the longest are about two inches in length, and one-third of an inch wide at their broadest part, but most of them are smaller; the larger and smaller ones alternate; unlike the rugæ of the stomach, they are permanent, and not obliterated by distension; they do not contain any of the circular muscular fibres, as the pyloric valve does. They begin in the duodenum, about one inch below the pylorus; in the lower part of the duodenum, they are very large, and succeed each other closely; about the middle of the jejunum, they begin to get smaller and wider apart; in the lower half of the ileum, they become less distinct, and in the lowest part of that intestine, they are altogether wanting. The *mucous* membrane of the small intestine, which also covers the valvulæ conniventes, is specially characterized by being everywhere closely beset with an immense number of minute thread-like processes, called *villi;* when immersed in water, these stand up and produce a flocculent appearance, resembling the pile of velvet; hence this mucous membrane has been termed *villous*. It also contains the intestinal glands, to be presently described, and other glands to be noticed, with the lacteals, in the section on Absorption. The nerves of the small intestine are derived immediately from the sympathetic system; on their finest branches in the submucous areolar tissue, are found multitudes of the microscopic ganglia, elsewhere noticed (p. 259); others exist between the circular and longitudinal muscular layers (Meissner, Auerbach).

The movements of the small intestine, depending on the contraction of its longitudinal and circular fibres, afford the most perfect example of *vermicular* or *peristaltic* movements. They consist, in the healthy state, of slow, successive, wavelike contractions, chiefly of the circular fibres, from the upper to the lower part of the intestine. They are noticeable in very emaciated persons during life, but are powerfully excited by exposure of the intestines to the air, especially when the abdominal aorta has been tied; they continue for a short time after death, and even when the intestine is removed from the body. By narrowing the small intestine, they urge gently onwards, from its upper to its lower end, the pulpy mixture of the alimentary substances and digestive juices, gently compressing these soft materials against the mucous membrane, passing them on, over the numerous valvulæ conniventes, and so undoubtedly aiding in absorption. The progressive contractions of the longitudinal fibres open and unfold the coils of the intestine, which otherwise might arrest the progress of its contents.

The peristaltic movements of the intestines are influenced, both through the cerebro-spinal and sympathetic nervous systems; this is shown by experiments on animals, by irritation of the solar plexus, spinal cord, and brain, and also by the peculiar effects of emotions on these movements; they are accelerated by moderate stimulation, and retarded or arrested or inhibited, by more powerful irritations. But, as they may continue after the intestine is removed from the body, it is possible that they are usually excited, either by the direct stimulation of the muscular fibres, or else, in a reflex manner, through the intervention of the minute nervous ganglia found in the submucous tissue, and in the circular and longitudinal muscular layers. The stimuli which excite these motions are, in either case, the digested food, and the various digestive fluids; of the latter, the bile is the most stimulating, and its importance as a regulator of the action of the alimentary canal, is well known.

Besides these intrinsic movements, the small intestine is acted upon jointly by the diaphragm and the abdominal muscles, which subject it to various degrees of pressure, and more or less alter its general position in the abdomen; such movements must aid in urging onwards the contents of the intestine. It has been estimated that the time occupied in the descent of the digested food along the small intestine is about three hours.

The *large intestine*, Fig. 89, *c* to *r*, extends from the small intestine to the termination of the alimentary canal. It measures usually about five or six feet, *i. e.*, about one-fifth of the whole length of the intestinal canal. Though much shorter than the small intestine, it is considerably wider, measuring from 1½ to 2½ inches in width, being widest at its commencement, and gradually narrowing as it descends. It pursues a remarkable course: commencing in the right iliac fossa, where the small intestine opens into it, it ascends along the right side to the under surface of the liver, then passes across between the umbilicus and the pit of the stomach, to the left side of the abdomen, whence it descends to the left iliac fossa, and, having described a double or *sigmoid* curve, enters the pelvis, through which it passes down, supported by the sacrum and coccyx. The large intestine is more or less arbitrarily divided into three parts; the first part named the *cæcum*, *c*, with its *vermiform appendix;* the second part, the *colon*, *co* to *co*, again subdivided into the *ascending*, *transverse*, *descending colon*, and *sigmoid flexure of the colon;* and the third part, or terminal portion, named the *rectum*, *r*.

The ileum, *i*, enters the inner or left side of the large intestine, *c*, a short distance above the commencement of the latter, which forms below the point of entrance, a pouch-like portion, about two inches in length, constituting the *cæcum*, so named because it is a *blind* pouch or cul-de-sac, Fig. 92, *c*.

Projecting from the lower and back part of the cæcum, is a narrow, coiled, and tapering tube, about 4 inches in length, and about as thick as a worm, hence named the *vermiform* or worm-like *appendix*, Fig. 92, *a*. It communicates with the cæcum by an opening, protected by a membranous ridge; its outer end is closed. It may be regarded as a part of the cæcum arrested in its growth, and is the homologue of the long cæcum found in Mammalia generally, the orang-outang, chimpanzee, and wombat being, however, exceptions.

The cæcum, and the ascending, transverse, and descending colon, with its sigmoid flexure, are distinguished from the small intestine, and also from the rectum, by their peculiar sacculated form. The *sacculi* of these parts, are arranged in three longitudinal rows, separated from each other by three intermediate bands. Their presence depends upon a peculiar arrangement of the coats of the intestine. These, as in the small intestine, are four in number, viz., proceeding from without inwards, the serous, the muscular, the areolar, and the mucous coats. The *serous* or *peritoneal* coat, is complete in only certain portions of the great intestine, viz., in the transverse part of the colon, the sigmoid flexure, and the upper part of the rectum; whilst the cæcum, the ascending and descending colon, and the lower part of the rectum, are closely fixed behind, and therefore receive only a partial covering from the peritoneum. The *muscular* coat consists, as usual, of external longitudinal and internal circular fibres. On the vermiform appendix, both sets of fibres form uniform layers. On the sacculated pouch of the cæcum, and throughout the whole length of the colon, however, the longitudinal fibres, thinly scattered over the sacculi, are chiefly collected into three long bundles, which form the three longitudinal bands between the sacculi. These bands, indeed, are *shorter*, from end to end, by nearly one-half, than the intermediate part of the intestine, which accordingly is puckered, and projects inwards in the form of sharp crescentic ridges between the dilated parts which form the sacculi. These sacculi become smaller and more scattered on the sigmoid flexure of the colon. On the rectum, the longitudinal fibres speedily form a thick stratum, evenly distributed over the whole circumference of the intestine, so that the sacculi disappear. The circular fibres cover the whole surface, but are accumulated in greater numbers on the ridges between the sacculi. Upon the rectum, however, they soon form a thick and uniform layer; the lower portion of this is particularly well developed, constituting the *internal sphincter muscle*, which constricts the lower part of the bowel, and assists the external sphincter muscle, situated beneath the skin, around the aperture of the intestine, in keeping the bowel closed. The *areolar* or submucous coat of the large intestine is attached loosely to the muscular coat, but more intimately to the mucous membrane; it is sacculated, and helps to maintain the form of the intestine; it supports the tender mucous coat, and furnishes a stratum, in which the bloodvessels, lymphatics, and nerves, ramify. The *mucous* coat, unlike that of the small intestine, follows strictly the form of the intestinal canal itself; for it is not thrown into proper folds, like the valvulæ conniventes, but only follows the concentric ridges between the sacculi. Moreover, it differs from the mucous membrane of the small intestine, in being somewhat thicker and paler, and in being perfectly smooth and entirely destitute of villi. In the cæcum and colon it is of a grayish-yellow color, but in the rectum it is darker, thicker, more vascular, and more loosely connected with the muscular coat. Its glands will be presently described. The nerves belong to the sympathetic system; in the submucous coat, their fine branches present microscopic ganglia, which are also found outside the muscular coat. The movements of the large intestine are not retarded by irritation of the splanchnic nerves.

At the junction of the lower end of the ileum, Fig. 92, *i*, with the cæcum, *c*, and colon, *co*, there is found a very perfect valve, the *ileo-cæcal* valve, or valve of Tulp or Bauhin, composed of two semilunar segments, having their free edges directed towards the large intestine. The end of the ileum is somewhat flattened on its upper and under aspects, and is here inserted into the left side of the large intestine. The flattened part of the small intestine carries in, with it, the side of the large intestine, and so forms the segments of the valve, which consist

Fig. 92.

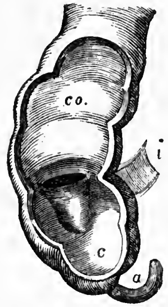


Fig. 92. The cæcum, and the commencement of the ascending colon, laid open in front, to show the ileo-cæcal or ileo-colic valve, at the junction of the small and large intestines. *c*, the cul-de-sac, named the cæcum, or blind intestine. *a*, vermiform appendix of the cæcum. *co*, part of the ascending colon. *i*, a piece of the ileum, or small intestine, entering the side of the large intestine, between the cæcum and colon, by a horizontal transverse fissure, bounded above and below, by the crescentic segments of the ileo-cæcal or ileo colic valve. Much reduced in size.

therefore of the coats of both intestines, excepting, however, the longitudinal muscular fibres and the peritoneal tunic. If the latter be carefully divided where it passes from one intestine to the other, the inserted part of the small intestine may be drawn out from the side of the large intestine, when the two segments of the ileo-cæcal valve disappear, and the small intestine seems to open widely into the side of the large intestine. In the natural condition, the segments of this valve are placed one above the other, and leave, between their free edges, a narrow, nearly horizontal slit, leading from the small into the large intestine. Each segment contains circular muscular fibres, areolar tissue, and two layers of mucous membrane, continuous with each other at the free edge of the segment. The mucous membrane of the surface turned towards the ileum is covered with villi; whilst that turned towards the large intestine is destitute of those processes.

Notwithstanding the active absorption which takes place along the whole length of the small intestine, its contents retain a pulpy consistence. By the peristaltic action of the circular muscular fibres, they are pressed through the slit-like opening between the segments of the ileo-cæcal valve, having passed which, they are received into the pouch of the cæcum, which now supports their weight, whilst the lateral position of the valve relieves it from pressure. Once having passed the valve, no force exerted upon the intestinal contents can ever return them into the small intestine, the valve-segments, owing to the elasticity and muscularity of all the parts, meeting closely together under every change of dimensions. Even after death, when these parts are removed from the body, water, poured into the colon, is, owing to the closure of the valve-segments, completely prevented from passing into the ileum. In the cæcum, the still pulpy residue of the processes of digestion and absorption undergoes further inspissation, perhaps also further digestion. By the combined and comparatively slow peristaltic action of the longitudinal bands between the sacculi, and of the circular fibres spread over the sacculi themselves, it is pressed upwards into the ascending colon, and, in like manner, onwards from sacculus to sacculus of the ascending, transverse, and descending colon, and, yet more slowly, through the sigmoid flexure of the colon into the rectum, acquiring, by gradual absorption, as it descends, its final state of inspissation, before it is expelled from the body. Undue pressure, or weight, is prevented by the sigmoid curve of the intestine. The external and internal sphincters, which close the rectum below, are kept contracted, in a reflex manner, by the action of the spinal cord. In defecation, these muscles are relaxed, whilst the intestine above contracts, the action being aided by expulsive efforts on the part of the abdominal and expiratory muscles generally, the diaphragm being fixed after closure of the glottis. The fibres surrounding the cardiac opening of the stomach must also close that aperture simultaneously.

Vomiting.

In the ordinary exercise of their functions in the digestive process, the œsophagus, the stomach, and the intestinal canal, manifest, as we have seen, movements of the so-called *peristaltic* kind, due to successive wave-like contractions of their muscular walls, excited partly through the nervous system, but also, especially in the case of the intestines, by the direct stimulation of the food upon them. But, under certain conditions, an undue local stimulation of the muscular fibres, or some wider irritation, operating through the nervous system, excites these organs to reversed, or so-called *anti-peristaltic* action, often accompanied with powerful associated movements of the abdominal muscles, and with certain peculiar states of the diaphragm and muscles of respiration generally, so producing the acts of *eructation*, *regurgitation*, *retching*, and *vomiting*.

The *eructation* of gaseous matters depends chiefly on the contraction of the walls of the stomach and œsophagus, aided slightly by that of the abdominal muscles and the diaphragm.

The act of *vomiting* is a more general and powerful movement, and often involves a contraction of the small intestines; but it depends essentially on a similar mechanism. Though an exceptional phenomenon, and, in disease, often a serious or fatal symptom, it is, in many instances, beneficial, relieving the stomach of indigestible, irritating, or poisonous substances, expelling from it morbid secretions, or even inducing a state of exhaustion, in some way favorable to ultimate recovery. *Retching* is unsuccessful vomiting.

Regurgitation is performed by the same mechanism as vomiting; but its effect is limited to the expulsion of small portions only of the contents of the stomach. There are persons who possess a sort of power of *rumination*, swallowing their food half chewed, and, after a time, returning it to the mouth, where it is fully masticated, and then reswallowed.

The actual contraction of the stomach, in *vomiting*, is sometimes felt; indeed, it has been witnessed. In a man, in whom the entire stomach protruded through a wound of the abdomen, forcible and repeated contractions of this organ were observed to continue for half an hour, till it was entirely emptied of its contents (Lepine). As a preliminary condition to the inverted action of the fibres of the stomach generally, the pyloric muscular ring contracts tightly, whilst the oblique fibres surrounding the cardiac orifice are always, and necessarily, relaxed; otherwise the contents of the stomach could not enter the œsophagus. The ineffectual attempts to vomit, sometimes noticed before the actual expulsion of the contents of the stomach, are due to the contraction of these cardiac fibres, which contraction ordinarily serves to retain the contents of the stomach, during any violent effort on the part of the abdominal muscles. The relaxation of these fibres, in vomiting, is immediately followed by an anti-peristaltic action of those of the œsophagus, movements which have been observed in the horse, after the injection of tartar emetic into its veins, and have been found to continue even when the œsophagus is separated from the stomach. It has been suggested, that the upward propulsion of the contents of the stomach or intestines, and of matters rising in the œsophagus, is due to a downward or peristaltic action meeting with resistance, and producing a central, or so-called axial current upwards (Brinton); but this explanation is not generally adopted, and anti-peristaltic movements certainly occur in animals.

The influence of the abdominal muscles in vomiting is obvious, and, indeed, Magendie suggested, that these muscles and the diaphragm were alone concerned in this act, the stomach being, as it were, passive, and merely compressed by the descent of the diaphragm, and the backward movement of the abdominal muscles. This view is supported by Béclard and Budge. The administration of tartar emetic, to an animal, or its injection into the veins, was said, by Magendie, never to produce contraction of the stomach. He found that, on drawing this organ out of the abdomen, no vomiting occurred; but, as soon as it was replaced in its normal situation, the action of the abdominal muscles, or the pressure of the hand, immediately produced vomiting; even after removal of the abdominal muscles, so as to leave only the linea alba, or the tendinous structure in the middle line of the abdominal walls, the descent of the diaphragm, according to that observer, still emptied the stomach. Moreover, on removing the stomach, and supplying its place by a bladder attached to the œsophagus, the contents of the former were forced upwards by the contraction of the abdominal muscles. It is, however, generally believed, that these experiments merely prove, that the abdominal muscles are powerful agents in expelling the contents of the stomach into the œsophagus, just as they assist, most materially, in the expulsion of the contents of the other hollow viscera. They do not show a completely passive condition of the stomach itself, which organ, as just stated, has been seen to be able to empty its own contents. In experiments on animals, when the abdomen is opened, the movements of the stomach are frequently so feeble and rapid, that they might escape observation.

It was supposed by Magendie that the diaphragm is actively concerned in vomiting, undergoing a movement of *descent;* but, the associated acts necessary to vomiting are *expiratory*, and the descent of the diaphragm is an inspiratory movement (Marshall Hall). At the moment of vomiting, the diaphragm, though more or less contracted, is certainly *fixed;* for, previous to each act of vomiting, a powerful inspiratory effort occurs, and the diaphragm of course descends; but the glottis is then closed, and any further movement, on the part of the diaphragm, is thus prevented, so that it probably remains passive in vomiting.

During vomiting, as in the second stage of deglutition, certain muscles draw the soft palate across the pharynx, and prevent the vomited substances from passing into the posterior nares; but when the abdominal muscles act very powerfully, these are sometimes ejected through the nose.

As elsewhere mentioned, vomiting is a *reflex* act, the pneumogastric nerves being the afferent nerves, the medulla oblongata and cord the excitable centres, and the nerves of the various muscles concerned, the efferent nerves. Sometimes it is *excito-motor*, and induced by *a local* stimulus, applied to the interior of the stomach itself, such as indigestible food, medicines, poisons, or diseased secretions; it may also be due to morbid irritability of this organ, from inflammation, ulceration, or other disease; or the cause of irritation may be distant, as in the intestines or some other part. In certain cases, as in sickness produced by a blow on the eyeball or on the shin, by strangulation of the intestine, or by a calculus in the kidney, the reflex act is *sensori-motor*, or accompanied by sensations which are always of a painful kind. The nausea and vomiting caused by tickling the fauces, by disagreeable tastes and odors, or by sickening sights, are likewise sensori-motor in their character. Sea-sickness is also an example of sensori-motor vomiting. *Emotional* causes may likewise excite this act. Emetic medicines, which operate just as readily when injected into the veins, as when introduced into the stomach, probably act directly on the reflex nervous centres concerned in vomiting; but they may operate on the extremities of the afferent nerves of the stomach. These are the pneumogastric nerves, irritation of which causes, amongst other results, contraction of the muscles of the abdomen, and vomiting. In the vomiting named *cerebral* vomiting, which occurs after concussion of the brain, and in certain diseases of that organ, the cause of irritation is central. In some individuals, vomiting can be performed voluntarily, this power being either natural, or else acquired by practice.

It is said that the act of vomiting but seldom occurs in the horse; and it has been attempted to explain this, by reference to the structure of the cardiac end of the stomach; but it would seem rather to be due to the very slight susceptibility of that animal to the action of emetic medicines.

THE DIGESTIVE FLUIDS.

The chemical processes concerned in the function of digestion, consist of peculiar reactions between the food and the various secretions of the alimentary canal.

The digestive fluids, which are added to, and act chemically on, the food in its progress through the alimentary canal, are as follow: first, the fluids of the mouth, consisting of the *mucus* secreted by the mucous membrane and glands of that cavitity, and the *saliva*, the product of the three pairs of salivary glands, named the *parotid*, *submaxillary*, and *sublingual* glands; secondly, the secretion of the stomach, named the *gastric juice*, formed by minute gastric glands, or follicles, embedded in the mucous membrane of that organ; thirdly, the *bile* secreted by the liver, and poured into the duodenum; fourthly, the *pancreatic juice* secreted by the pancreas, and also added to the food in the duodenum; and lastly, the mucus and the *intestinal juices*, secreted by the mucous glands and by the so-called tubuli, which exist in vast numbers in the mucous membrane of every part of the small and large intestines. Each of these fluids exercises a special transmutation on one or more of the proximate constituents of the food, the tendency of such changes being to convert those constituents, from an insoluble and unabsorbable condition, into a state of solution, or into a state in which they can be absorbed, that being the ultimate object of the digestive process.

Sources and Composition of the Buccal Mucus and Saliva.

The *mucous glands* of the mouth are named, according to their position, *labial*, *buccal*, *molar*, *palatal*, and *lingual*. These are chiefly compound racemose glands, forming rounded masses beneath the mucous membrane, and opening into the mouth by their proper ducts. At the base of the tongue are a few simple follicles, and some follicular depressions, having little closed sacs in their walls, like the follicles of the tonsils. The tonsils themselves probably also furnish some mucous secretion. Beyond the mouth, the pharynx possesses numerous simple follicles, and its upper part, compound racemose glands. Their secretion lubricates the parts, and also the surface of the food. It may likewise aid the saliva in its chemical action. Throughout the whole length of the œsophagus, and especially in a circular group around its lower end, there are also numerous compound mucous glands, which perform similar offices.

Of the three pairs of *salivary glands*, the *parotid* glands are by far the largest, weighing from 5 to 8 drachms each. They are placed one on each side of the face, between the ear (παρά, near, οὖς, ὠτός, the ear) and the lower jaw, which they overlap, being there supported by their ducts and bloodvessels, and by a strong fascia. The facial nerves pass through the glands. The principal mass of each gland occupies the position above indicated, and likewise penetrates amongst the muscles and vessels of this region; but a secondary or *accessory* portion, *socia parotidis*, extends forwards along the excretory duct. This canal, named the *Stenonian duct*, runs forward from the gland, over the masseter muscle, passes obliquely through the buccinator muscle, and, opposite the second upper molar tooth, opens by a narrow orifice into the mouth. It is about $2\frac{1}{2}$ inches long, and about the diameter of a crowquill, but its orifice is very minute. The gland itself consists of numerous compressed lobes, held together by the ramified ducts and bloodvessels, and by areolar tissue. The lobes are again divided into lobules, each of which is a minute racemose gland, the branched ducts of which terminate in vesicles, about $\frac{1}{1200}$th of an inch in diameter, Fig. 42, C, each being surrounded by a network of capillaries. The saliva, secreted from the blood into these vesicles, flows along the smaller branches of the ducts, into the main canal or duct of Steno, and is thence poured into the mouth at a place suitable for moistening the dry food, and for being mixed with the alimentary mass. The *submaxillary* glands are placed, one on each side, beneath the horizontal part of the lower jaw, attached by their ducts and bloodvessels, and supported by the cervical fascia and certain muscles. Each gland is of a roundish shape, and weighs from 2 to $2\frac{1}{2}$ drachms; its structure resembles that of the parotid. Its chief duct, thinner than that of the parotid, is named the Whartonian duct, and is about 2 inches long; it runs forwards between the muscles, beneath the sublingual gland, to the side of the frænum of the tongue, where it opens upon a small eminence close to the duct of the opposite side. These glands, therefore, discharge their saliva, not outside the jaws, like the parotid glands, but inside the lower dental arch, their secretion being pressed up into the mouth by the motions of the tongue. The *sublingual* glands, the smallest of the salivary glands, are somewhat almond-shaped, and weigh each about one drachm; they form two narrow, oblong ridges, about $1\frac{1}{2}$ inch long, placed, one on each side, beneath the tongue. Their structure resembles that of the other salivary glands, but, instead of having a common duct, the several lobules open into from eight to twenty ducts, named the Rivinian ducts, some of which, including one large duct named the duct of Bartholin, join the Whartonian duct, as it runs for a certain distance immediately beneath the gland. The saliva from the sublingual glands flows into the mouth beneath the tip and sides of the tongue.

The mechanical flow of the saliva into the mouth is aided by the contraction of the muscles of the tongue and jaw engaged in mastication; on opening the mouth before a looking-glass, and then turning up, and stiffening, the tongue, the saliva is sometimes seen to be ejected a considerable distance, from the orifices of the Whartonian ducts.

The salivary glands all receive branches from the sympathetic nervous system; the parotid glands are likewise supplied by the fifth pair (its auriculo-temporal branch); whilst the sublingual and submaxillary glands receive nervous filaments from the chorda-tympani branches of the facial nerves. The saliva flows intermittently; and its secretion is excited through the nervous system, by the agency of which, the quantity of this and other secretions, is chiefly regulated (p. 264). Thus, the presence of food, especially of dry food, in the mouth, and even the introduction of food into the stomach through a gastric fistula, stimulates the flow of saliva; salt, vinegar, pepper, and other condiments, and particularly tobacco, and the root of the pellitory of Spain, have a still more powerful effect; these furnish examples of reflex stimulation of the salivary secretion. The afferent nerves concerned, are the gustatory branches of the fifth pair, and the glosso-pharyngeal nerves; the efferent nerve-fibres are contained in the chorda-tympani branches of the facial nerves, or in the auriculo-temporal branches of the fifth pair. The nervous centres are the submaxillary ganglia, and the cerebro-spinal axis. Besides this, the saliva is excited to flow by ideational or other mental stimuli, such as the sight of food, or even the thought of it. The act of speaking, and also that of vomiting, are preceded by a flow of saliva. Fear diminishes or arrests it. Irritation of the fourth ventricle, and the presence of certain substances in the blood, especially of mercury, likewise increase the flow of this secretion. The effect of mercurialization in exciting a flow of saliva is specific.

The mode in which the nervous system influences the secretion of saliva, has been elucidated by the interesting experiments of M. Bernard. When the sublingual and submaxillary glands, exposed in an animal, are at rest, little or no saliva being formed, the veins are seen to contain a moderate quantity of dark blood. On now stimulating the glands, in a reflex manner, by the application of vinegar to the tongue, the arteries supplying them dilate, the flow of blood through these vessels becomes quicker, even the veins pulsate, the venous blood is of a bright red color, and there occurs a copious flow of watery saliva. The afferent nerves concerned in this reflex act, are obviously branches of the gustatory and glosso-pharyngeal nerves; the efferent fibres are contained in the chorda tympani; for if either this or the facial, from which it is derived, be cut, the active phenomena above described, all gradually cease, but they are again excited by irritation of the *distal* ends of the divided nerves. If the facial nerve be drawn out from the cranial cavity, irritation of the glosso-pharyngeal no longer increases the flow of saliva. The efferent nerves of the parotid glands are said, by Eckhard, to proceed, not from the chorda tympani or facial, but from the auriculo-temporal branch of the fifth pair. As already stated (p. 264), irritation of the sympathetic branches supplying the sublingual and submaxillary glands, has an opposite effect to that of stimulating the fibres of the chorda tympani; the secretion from the glands then becomes scanty and thick, the arteries small, the flow of blood through the gland diminished and retarded, and the venous blood dark. To explain these opposite phenomena, it is assumed that the sympathetic nervous centres cause a contraction of the muscular coats of the smaller arteries; whilst the cerebro-spinal centres inhibit this power, and so induce a relaxed condition of the arterial coats. The efferent effect, conveyed through the chorda tympani nerve-fibres, is therefore not *motor*, but of a special kind, controlling, or inhibiting the action of the sympathetic nerve-fibres and centres. This example will suffice to illustrate the mode in which secretion generally is believed to be influenced through the nervous system. Irritation of the sympathetic nerves does not alter the quality, but only lessens the quantity, of the secretion of the parotid glands. According to Eckhard, great numbers of mucous corpuscles, exhibiting intrinsic movements, like those of the Amœba, are found in the viscid secretion of the sublingual and submaxillary glands, after irritation of their sympathetic nerves; such corpuscles, but in smaller number, exist, as we shall see, in ordinary saliva.

The chemical composition of the saliva is, according to Dr. Wright, as follows:

Water, ...	98.81	. . =	98.81
Ptyalin, or Salivin, .	.18	Solids . =	1.19
Fatty matter, . .	.05		
Albumen with Soda, .	.17		
Mucus, ...	.26		
Ashes, ...	.41		
Loss, ...	.12		
	100.		100.

The saliva, thus constituted, is a transparent watery fluid, destitute of smell; its specific gravity varies from 1002 to 1008. Besides fine granular particles, mucous corpuscles, derived, for the most part, from the lingual and tonsillar glands, and epithelial cells detached from the mouth, the saliva contains the so-called *salivary corpuscles*, spheroidal nucleated cells, somewhat resembling the white blood-corpuscles, which undergo Amœba-like changes in form, and exhibit a molecular movement in their interior.

The quantity of saliva secreted in twenty-four hours by all the glands, has been estimated at from 1 to 3 lbs.; but it differs according to the nature of the food, and the intervals between the meals. Its flow is increased by mastication, but is arrested by the cessation of that movement. The saliva from the parotid gland is very thin and watery, and becomes more abundant during mastication; that from the submaxillary, and especially from the sublingual gland, is more viscid, and flows more constantly, for purposes of speech. The parotid glands, when active, are said to secrete from eight to ten times their own weight in one hour. When first secreted, and especially during active secretion, the saliva is alkaline; that of the submaxillary gland is less so than that of the parotid. In fasting, the moisture of the mouth is nearly neutral, or even acid, at that time consisting probably almost entirely of mucus. The *ptyalin* or *salivin*, the most important constituent of the saliva, is an albuminoid substance. Of the salts, the tribasic phosphate of soda is probably the cause of the alkalinity of the secretion; besides this, there are found chlorides of sodium and potassium, sulphate of soda, phosphates of lime and magnesia, and oxide of iron. The tartar of the teeth is formed by a deposit of these earthy salts, mixed with mucus, and the remains of bacteria or vibrios; it contains 20 per cent. of animal matter. Urea has also been found in the fluids of the mouth, and traces of ammonia, the results of decomposition. Thus far, the salts of the healthy saliva resemble those of the blood; but it contains a peculiar and remarkable salt, named the *sulphocyanide of potassium*, which strikes a deep red color with a solution of a persalt of iron.

Source and Composition of the Gastric Juice.

When the soft pulpy mucous membrane of the stomach is examined under a moderate magnifying power, it presents a delicate honeycomb appearance (Fig. 93), caused by numerous shallow, hexagonal, or polygonal, depressions, named the *cells* or *alveoli* of the stomach; near the pylorus, these measure $\frac{1}{100}$th of an inch in width, but elsewhere are smaller and less distinct, measuring only $\frac{1}{200}$th to $\frac{1}{350}$th of an inch. Between the alveoli are slightly elevated ridges, upon which, especially near the pyloric end of the stomach, are minute processes, which somewhat resemble villi, and are more distinct in the

Fig. 93.

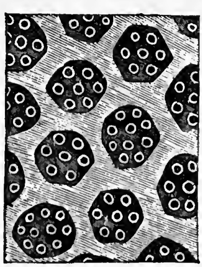


Fig. 94.

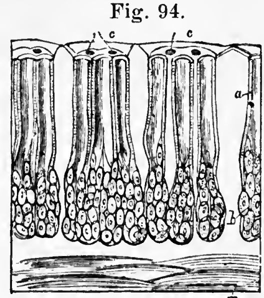


Fig. 93. Minute portion of the surface of the mucous membrane of the human stomach, showing the polygonal depressions or alveoli, with the elevated ridges between them. At the bottom of the alveoli, are seen the open mouths of clusters of the tubuli of the stomach, or gastric tubuli. Magnified 60 diameters. (After Boyd.)

Fig. 94. Perpendicular section through a small piece of the mucous membrane of the stomach, to show the clusters of the gastric tubuli. *a*, neck of a single tubule. *b*, dilated end or fundus, filled with glandular epithelial cells. *c*, orifices of the tubuli, at the bottom of the alveoli. *m*, muscular bundles of the muscular coat. (After Kölliker.) Magnified 40 times.

infant. No lacteals, however, have been detected in them. At the bottom of the alveoli are clusters of minute spots (Fig. 93), which are the orifices of tubular follicles. These follicles, called the *gastric* *glands* or *tubuli*, secrete the gastric juice; they are arranged, side by side, in little groups (Fig. 94), perpendicularly to the surface of the membrane, and form almost its entire substance. At the pyloric end of the stomach, where the mucous membrane is thickest, the tubuli are the longest, measuring nearly $\frac{1}{20}$th of an inch in length; towards the cardiac end, where the mucous membrane is thinnest, they are less thickly set, and become gradually shorter, measuring only $\frac{1}{60}$th of an inch in length; their average diameter is about $\frac{1}{360}$th to $\frac{1}{500}$th of an inch, the orifices, *c*, being somewhat narrower. Each follicle is somewhat dilated, or flask-shaped, at its deeper or blind end; the larger follicles are sometimes convoluted or varicose, and sacculated at the blind end, or even subdivided into two, or sometimes, as in the pyloric portion of the stomach, into as many as six or eight short sacculated tubuli. These tubuli consist of extensions of the gastric mucous membrane. The upper third of each tubule, next to its orifice, is lined by columnar epithelial cells (Fig. 95, *a*), arranged perpendicularly on the basement membrane. This epithelium is continuous with that at the bottom of the alveoli, and on the interalveolar ridges, and indeed is similar to that lining the stomach generally. In the lower two-thirds of each tubule the epithelium changes its character, being composed of soft, roundish, oval, or compressed nucleated cells, *b*, which, very much larger than the cylindrical epithelial cells, and distended with granular matter, almost or completely block up the cavity of the tubule. These soft epithelial cells are named the *peptic* cells, because in or by them, the gastric juice, or, at least, its characteristic animal substance, called *pepsin*, appears to be formed. Some of these cells are present as microscopic elements of the gastric juice. The tubuli, which are said to number about five millions, are sometimes named the

Fig. 95.

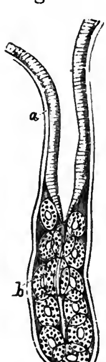


Fig. 95. Single gastric tubulus, or peptic gland, more highly magnified. *a*, neck of the tubule, lined with columnar epithelium. *b*, dilated lower end, or fundus, of the tubule, filled with oval nucleated glandular epithelial cells, or peptic cells. Magnified 70 diameters.

peptic glands. They are surrounded by a fine capillary network; minute arteries and veins pass up and down between them, and end in a capillary plexus on the bottom of the alveoli, and on the interalveolar ridges. The unstriped muscular fibres found in the submucous coat are placed immediately beneath these glands, and probably assist in expelling their secretion.

Besides these proper gastric or peptic glands, there are found, especially near the pylorus, clusters of larger simple and compound *mucous* glands, which are lined throughout with cylindrical epithelium, and are supposed to secrete gastric mucus.

In certain conditions of the stomach, especially during and after digestion, and also in irritation and inflammation of this organ, and nearly always in the stomachs of infants, numerous small, milky-white, elevated spots are seen scattered over the mucous membrane. These consist of lenticular *closed* sacs, not opening on the surface; they are filled with a white, semifluid and finely granular substance. They resemble the closed sacs of the tonsils, and of the so-called solitary and agminated glands of the small intestine, to be hereafter noted; like them, they are now considered to be appendages of the absorbent system. The lymphatics of the stomach form a fine network near the surface of the mucous membrane, and coarser plexuses in the submucous coat, all intimately connected together.

The *gastric juice*, during the digestive process, or under the excitement of condiments, small stones, and other irritant bodies, exudes from every part of the mucous membrane of the stomach, which then assumes a bright red hue. The secretion pouring from the tubules, oozes from the alveoli in minute drops, which speedily run together, and cover the whole mucous membrane. This has been seen by Dr. Beaumont and others, in the case of Alexis St. Martin, a Canadian voyageur, the interior of whose stomach was exposed by a gunshot injury.

The condition of the stomach, and the formation of the gastric juice, as of other secretions, are influenced by the nervous system. It was shown, by Dr. John Reid, that the division of both pneumogastric nerves, in the neck of a dog, in the first instance, arrested digestion; but that, if the animal lived sufficiently long, the process might be restored; for then, generally, the state of emaciation, which followed the experiment, was removed, acid and partly digested food was vomited, and absorption and chylification took place. This restoration of function was not due to reunion of the divided nerves, for portions of the nerves were removed, or care was taken to keep the cut ends apart. Bernard also found, that, on division of these nerves, the stomach became pale, its walls relaxed, and the formation of gastric juice was instantly arrested, digestion being thus stopped. On the other hand, galvanizing these nerves increased the gastric secretion. According to Longet, however, the pneumogastric nerves are rather the motor nerves of the stomach, their division, as he believes, chiefly affecting the movements of that organ; for he found that milk, introduced into the stomach one or two days after the operation, always became coagulated; whilst, although large portions of food were only acted upon on the surface, owing to the paralysis of the muscular fibres, and the necessary absence of the churning movements of the stomach, yet small portions were actually digested. By Budge, it is believed, that the very decided effect of division of these pneumogastric nerves on digestion, noticed by Reid and Bernard, was owing to those nerves having been cut in the neck, so as to interfere with respiration, and thus disturb the whole economy; for, he observed that, on dividing them in the rabbit, close to the cardiac orifice of the stomach, no interference with the appetite, the gastric secretion, or digestion, occurred. Although, therefore, the secretion of the gastric juice appears to be influenced by the cerebro-spinal nervous system, through the pneumogastric nerves, it cannot be said to be dependent upon it. The effects of mental emotion in arresting digestion, sufficiently prove this influence.

It has been stated by Bernard, that galvanism applied to the sympathetic nerves of the stomach causes an immediate cessation of its secretion, this effect being the reverse of what happens when the pneumogastric nerves are so stimulated. If these two results are confirmed, they would correspond with those already detailed (p. 522) as to the effects of stimulation of the sympathetic nerves and the chorda tympani, on the secretion of the sublingual and submaxillary glands. Neither division of the splanchnic nerves, nor section of the pneumogastrics *upon* the stomach, that is to say, after the latter have received the fibres from the former nerves, has appeared to interfere much, or at all, with the gastric secretion (Schiff and others); even the cœliac plexus, and the neighboring ganglia, have been removed without permanent effect (Budge). It would seem impossible, however, in any such experiments, to remove, or divide *all* the sympathetic nerves of the stomach. Finally, the influence of this part of the nervous system on the gastric secretion is uncertain; and it is not yet shown that the secretion is either arrested by, or depends on, the sympathetic system.

The quantity of the gastric juice secreted appears to be enormous. In dogs, the daily quantity has been calculated as $\frac{1}{20}$th (Corvisart) or $\frac{1}{10}$th (Lehmann) part of the weight of the body; the latter ratio would give 14 lbs. in a man of 140 lbs. weight, a quantity equal to rather more than 11 pints daily. That this estimate, however large, is not extreme, is shown by the fact that, in a case of gastric fistula, in a woman, the estimated daily quantity was 30½ lbs. av., the weight of her body being 116 lbs. From observations on dogs, having artificial gastric fistulæ, the secretion appears to be less abundantly excited by mechanical, than by chemical or special irritants, such as salt or pepper; acid food excites a less abundant flow than food made slightly alkaline; but alkali in the solid state induces an abundant secretion of mucus. Too powerful mechanical irritation has a similar effect, lessening, or arresting, the secretion of proper gastric juice, and, in both cases, vomiting, and the passage of bile into the stomach, may take place. Powerful chemical irritants arrest digestion, and cause signs of inflammation. The effect of cold water, or ice, is, after first causing the gastric membrane to be pale, ultimately to increase the flow of blood to it, and to excite a very active secretion; ice, in larger quantity, causes shivering, and delays digestion. A high temperature, even a small quantity of boiling water, produces collapse and death within four hours, causing redness, turgescence, and ecchymosis of the mucous membrane (Bernard). Dr. Beaumont found that, on injecting into the human stomach only 2 oz. of water at 50°, the temperature of this organ was depressed to less than 70°, and required more than half an hour to regain its normal standard, viz., about 100°.

The specific gravity of the gastric juice, in man, is 1002.5; in the dog, 1005. The quantity of solids is about .5 per cent. It is a colorless, or pale yellow, transparent, slightly viscid, and strongly acid fluid, having a faint smell. It resists putrefaction, and is rendered turbid on boiling. Its composition, mixed with a little saliva, is as follows (Schmidt):

Water,	994.4
Pepsin, with other organic matter,	3.2
Salts,	2.2
Free hydrochloric acid,	.2
	1000.

The gastric juice of the dog contains ten times as much free acid, and five times as much organic matter; that of the sheep, six times as much acid, and a little more organic matter; that of the horse, is somewhat more concentrated.

The small quantity of solid matter in the gastric juice, is remarkable, considering its extremely active powers. The *pepsin*, its characteristic constituent, is a neutral, albuminoid substance, slightly soluble in water, forming, on evaporation, a grayish viscid mass, and having a strong affinity for acids. It is precipitated by tannin, acetate of lead, caustic alkalies, alum, and alcohol. The saline matters consist chiefly of alkaline and earthy chlorides and phosphates. A small amount of lactic acid exists in the gastric juice, but whether as a product of secretion, or of decomposition, is not certain; by Bernard and others, it is even believed to be the special acid of the gastric juice. Acetic, butyric, and other volatile acids are certainly the result of changes in the food. The presence of free hydrochloric acid is undoubted, inasmuch as chlorine is found in the gastric juice in larger quantity than the bases which could combine with it; and moreover, this acid has been obtained by the method of dialysis, and therefore independently of chemical decomposition (Graham). Its existence affords a singular example of the liberation of a mineral acid from its strongly combined base, by an organic process in the living animal economy. The source of this acid is probably chloride of sodium, or common salt; and the seat of its decomposition, like that of the formation of the pepsin, is probably the soft glandular epithelial cells, or peptic cells; but it has been suggested, that it may be secreted by the columnar epithelial cells of the upper part of the tubuli and gastric mucous membrane generally (Brinton). It is supposed by Brücke, that the pepsin is neutral when contained in the peptic cells, and becomes acidified only after its escape from these cells; for the pepsin obtained from the gastric mucous membrane of the animal, after its acidity has been removed by washing, is neutral. It has also been shown by Bernard, that, whereas the introduction of lactate of iron and ferrocyanide of potassium into the blood of a living animal, produces no blue color in the blood, tissues, or secretions generally, nor even in the gastric glands, yet the surface of the mucous membrane of the stomach is stained blue. Other parts of the body, moreover, become blue on the application of an acid. This experiment, therefore, also favors the supposition that the acid of the gastric juice is formed near, or at, the surface. It is uncertain whether the separation of the hydrochloric acid, is a direct result of an act of secretion by secreting cells, or whether it is a secondary product of a decomposition, induced by the action of some other intermediately formed free organic acid. The quantity of solid matter in the gastric juice, and the relative amount of organic and saline constituents, differ in different animals. It is universally acid, but the nature of the acid, as well as that of the organic peptic agent, may vary in certain cases, according to the species, age, and diet of the animal. When the stomach is at rest, its mucous secretion is neutral or alkaline, semi-opaque, and more viscid than the gastric juice.

[In 1856 an opportunity was presented the editor of examining and experimenting upon Alexis St. Martin, the Canadian, with a fistulous orifice in his stomach, the result of an accidental gunshot wound received when quite a lad.

Several questions relating to the physiological action of the stomach may be regarded as still unsettled; among these is that relating to the nature of the acid contained in the gastric juice, and the influence of this secretion upon the various alimentary principles as classified by Prout, viz., saccharine, oleaginous, and albuminous food.

The analyses, conducted by the careful hand of my colleague, Prof. R. E. Rogers, were made upon the fluids obtained from the stomach while digestion was in progress, for that which was drawn from the stomach while fasting was found to be putrescent. In every instance, and with all kinds of food employed, the reaction of the fluid of digestion was *acid*, while that of the *empty* stomach (as shown by the introduction of test papers through the fistulous orifice), and of the fluid obtained by mechanical irritation, was as distinctly *neutral*. The *temperature* of the stomach, while digestion was in progress, was about 100° to 101° Fahr., when empty about 98° to 99°.

The fluid for examination was obtained by placing the man upon his right side, and gently introducing a large-sized gum-elastic catheter or a small glass speculum. He was then allowed to turn himself towards the opposite side, when the contents of the stomach would readily flow out. In no instance was food allowed to remain in the stomach longer than two hours. The mucous membrane of the empty stomach presented a pale pink color, as described by Beaumont, with the surface lubricated by mucus: when digesting, its color was deepened, and the peristaltic motion could be distinctly seen. During all the experiments St. Martin retained his usual good health, was in excellent spirits, and took his food with appetite.

All observers, in whatever way they obtained gastric juice, agree on one point,—the existence of an acid reaction of the fluid of digestion;

but as to the *nature* of that acid, they differ widely, some contending that it is *organic*, others *mineral;* some that it is acetic, lactic, or butyric, others that it is hydrochloric acid, or the acid biphosphate of lime. The latter theory, advanced by Blondlot, has been disproved by Dumas, Bernard, and Melsens, who have shown that not only the carbonate, but also the basic phosphate of lime are soluble in gastric juice, as are also zinc and iron with the evolution of hydrogen gas,—properties which a solution of acid phosphate of lime does not possess.

Dr. Prout, in 1824, Dr. Dunglison, in 1833–34, and Braconnot, in 1835, state that they obtained evidences of free hydrochloric acid in gastric juice, the first in the stomach of rabbits killed while digesting, the second in the fluid obtained by Dr. Beaumont from St. Martin, and the last in gastric juice obtained by sponging the stomachs of animals. More recently, Bernard and Barreswill, Pelouze and Thompson, have been led to believe, from their own experimental researches, that *lactic* acid is the agent upon which the characteristic reaction of the gastric juice depends, and attribute the presence of hydrochloric acid in the free state to the decomposition of the alkaline chlorides by the lactic acid at a high heat. Hence, supposing *lactic* acid to be present in the fluid of digestion, with chloride of sodium, the fluid which passes over by distillation will, at first, be destitute of hydrochloric acid; but as the liquid becomes more concentrated, and the temperature rises, hydrochloric acid will pass over. Lehmann denies the power of (hydrochloric?) acid to decompose the chloride of sodium, but asserts that chloride of calcium is decomposed by lactic acid, even in vacuo; and hence it is not surprising that pure gastric juice should develop vapors in vacuo, which, when passed into a solution of nitrate of silver, should form chloride of silver.

Still more recently, Messrs. Bidder and Schmidt declare, as the result of eighteen corresponding analyses, "that pure gastric juice of carnivora, after eighteen to twenty hours' fasting, contained *free hydrochloric acid* only, without a trace of lactic or any other organic acid; while the gastric juice of herbivora contains, with free hydrochloric acid, small quantities of lactic acid, which may, however, be referred to their more amylaceous food." Grunewald's experiments led him to the conclusion that the acid was an organic one, while Schroeder maintains that the fluid obtained by irritating the stomach by peas, owed its reaction to hydrochloric acid.

With a view of determining this question, the series of experiments referred to were instituted, and conducted in the most careful manner, and as a result, the following conclusions were arrived at, though some of them were at variance with the doctrines maintained by the writer for many years previous.

1st. That the secretions of the stomach, when digesting, are invariably acid.

2d. That the acid reaction was not due to phosphoric acid.

3d. That if hydrochloric acid was present, it was in very small quantities.

4th. That the main agent in producing the characteristic reaction was *lactic acid.* (*Philad. Med. Examiner*, July & Sept., 1856; *Jour. de Physiologie*, Jan., 1858.) F. G. S.]

Source and Composition of the Bile.

The *liver* is a solid organ of a dark reddish-brown color, measuring 10 or 12 inches from side to side, about 7 inches from front to back, and about 3 inches in thickness at its posterior margin, its anterior edge being, however, thin. Its average bulk has been differently estimated at 88 or 100 cubic inches; its weight varies from 50 to 60 ounces. It is the largest secreting gland in the body, and with the exception of the lungs, occupies more space than any other organ. It secretes the bile, the importance of which office is shown by the fact, that the liver is found in all the Vertebrate, and in most of the non-Vertebrate animals.

The substance of the liver has a sp. gr. of 1050 to 1060. It has an acid reaction; its composition, in Man, in 100 parts, is said to be as follows (Beale). The extractive matters mentioned include the amyloid substance named glycogen, a certain quantity of sugar, with traces of inosite, hypoxanthin, xanthoglobulin, urea, and uric acid.

Water,			68.58
Fatty matters,	3.82	Total solids,	31.42
Albumen,	4.67		
Extractive matters,	5.40		
Alkaline salts,	1.17		
Earthy salts,	.33		
Vessels, &c., insoluble in water,	16.03		
			100.

The liver is placed in the upper part of the abdomen, beneath the diaphragm, reaching from back to front, and from the right side partly over into the left. Its upper surface is smooth and convex, and is adapted closely to the diaphragm. Its thick posterior border rests on the pillars of the diaphragm and on the vertebral column, being hollowed out opposite the latter, and presenting also a deep notch for the ascending vena cava. The thin anterior border is concealed, in the recumbent posture, by the lower ribs and their cartilages, but descends a little below these parts, in standing, especially during inspiration, when the diaphragm descends (see Fig. 13). This border is slightly notched, a little to the left of the middle line. The right border of the liver, nearly as thick as its posterior border, descends lower than the left, and is in contact with the diaphragm; the left border, thinner even than the anterior margin, extends upwards to the cardiac end of the stomach. The under surface, Fig. 96, is concave and very uneven, presenting various slight depressions, where it touches the stomach, the duodenum, the bend of the ascending and transverse colon, the right kidney, and its supra-renal capsule; this surface is also marked by special fossæ or fissures for the lodgment of the gall-bladder, *g*, and for the entrance and exit of bloodvessels, lymphatics, nerves, and ducts.

The greater part of the surface of the liver is covered by the peritoneum, by which its slight changes of position in the abdomen, are facilitated. At certain points, this serous membrane passes, in the form of folds, to the abdominal walls, and thus aids in supporting or suspending the liver. These folds constitute four of the five ligaments of the liver. The *broad*, *suspensory*, or *falciform* ligament is a triangular double fold, attached by one border to the diaphragm, and to the anterior wall of the abdomen as far as the umbilicus, and by the other, to the upper surface of the liver, as far as the notch in its anterior margin; the remaining border is free, and extends from the notch in the liver to the umbilicus. This latter border contains a dense fibrous cord, named the *round ligament*, *ligamentum teres*, Fig. 96, *a*, which is formed by the remains of the umbilical vein, a structure which becomes obliterated after birth. A considerable portion of the thick posterior border of the liver is attached, by areolar tissue, to the diaphragm, and is therefore not covered by peritoneum, which, instead, passes from one part to the other, forms the so-called *coronary ligament*, and thus helps to suspend the liver to the diaphragm. The *right* and *left lateral ligaments* are triangular peritoneal folds, strengthened by intermediate fibrous tissue, which pass from each side of the liver to the diaphragm.

The liver is described as consisting of five lobes. Thus, it is divided by the notch in its anterior margin, and by the line of attachment of the suspensory ligament to its upper surface, into a *right*, *l*, and *left* lobe *l'*, the former being quadrangular in shape and the latter somewhat triangular, and constituting only about one-fifth of the entire organ. A deep fissure on the under surface also marks the limit between these lobes. On its under surface, the right lobe is further divided into the following smaller lobes, viz., the *Spigelian lobe*, a pyramidal mass, situated near the hinder border; the *caudate* or *tailed* lobe, passing forwards from the Spigelian lobe; and, lastly, the *square* or *quadrate* lobe, placed between the gall-bladder and the line of demarcation between the right and left lobes.

The liver also presents, on its under surface, five *fossæ* or *fissures*, in which are contained important vessels and ducts. The *longitudinal* fissure passes, from before backwards, between the right and left lobes, and is divided into two parts; the anterior part is named the *umbilical* fissure, which contains before birth the umbilical vein, but afterwards, the *round ligament*, the fibrous cord left after the obliteration of that vein; the posterior part, called the *fissure of the ductus venosus*, contains, before birth, the large vein so named, and subsequently the fibrous cord remaining after its closure. Thirdly, extending nearly at right angles from the junction of the umbilical fissure with the fissure of the ductus venosus, to about the centre of the right lobe, is the *transverse* or *portal* fissure, or *porta*, the *gate*, sometimes called the *hilus* of the liver; through this the chief bloodvessels, lymphatics, nerves, and ducts of the liver pass in and out (see Fig. 96). The principal vessel which enters here, is a large vein, the vena *portæ* or *portal vein*. The fourth fissure is the notch on the posterior border of the liver, which joins the fissure for the ductus venosus, and lodges the ascending vena cava and the orifices of the so-called *hepatic* veins. The fifth fissure receives the upper side of the gall-bladder.

The liver possesses three sets of bloodvessels, two conveying blood to it; viz., the *portal vein* and the *hepatic artery*, and a third set, the *hepatic veins*, which carry the blood from it. The liver in Man, and in the Vertebrata generally, is remarkable for being supplied, partly by venous, and partly by arterial, blood, for the portal vein, contrary to the usual office of a vein, conveys blood into the liver. This *portal* vein, Fig. 97, *p*, is formed by the union of the veins of the abdominal organs of digestion and sanguification, excepting the liver itself, viz., by those of the stomach, *s*, small intestine, *i*, large intestine, *co*, except

Fig. 96.

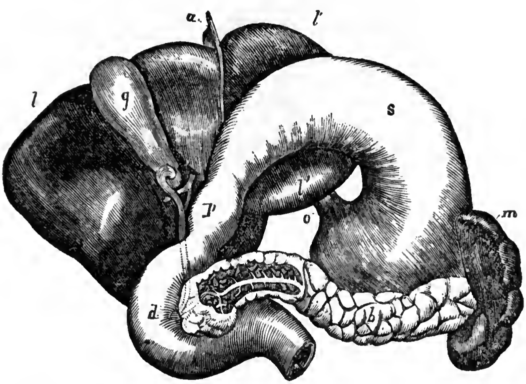


Fig. 96. View of the under surface of the liver and stomach, lifted up, to show the duodenum, pancreas, and spleen, and their mutual relations. *s*, the under or posterior surface of the stomach, which is lifted up. *o*, the œsophagus. *p*, the pylorus. *d*, the horseshoe curve of the duodenum, or first part of the small intestine. *l*, under side of the right lobe of the liver. *l'*, *l'*, under side of the left lobe, the liver being turned up. *a*, small piece of the round and suspensory ligament of the liver. *g*, under side of the gall-bladder, ending below in the cystic duct: this is joined by the hepatic duct, formed by the union of a right and left duct, from the two lobes of the liver. The common duct, resulting from the union of the cystic and hepatic ducts, the ductus communis choledochus, or common bile duct, passes down, as shown by the dotted lines, behind the duodenum, to end with the pancreatic duct, also shown by dotted lines, by a common orifice, on a papilla, in the duodenum. *b*, the pancreas, attached to the curve of the duodenum; it is partly dissected to show its central duct, with its branches, the end of it being indicated by dotted lines, as above described. *m*, the spleen, attached to the left end of the stomach and pancreas: its anterior notched border is seen. The drawing indicates the dark color of the spleen and liver, and the white color of the pancreas.

the lower two-thirds of the rectum, *r*, of the gall-bladder, pancreas, *d*, and spleen, *m*. The veins from these parts unite to form the superior mesenteric and splenic veins, which join to constitute the vena portæ. The venous trunk thus formed, *p*, is of great size, being more than half an inch in diameter. It ascends to the under surface of the liver, and entering the portal fissure, there divides into a right and left branch, for the corresponding lobes of the liver, in the substance of which it ramifies like an artery. The *hepatic artery*, which also conveys blood to the liver, is a branch of the *cœliac axis*, a short trunk given off from the abdominal aorta, *a;* it enters the liver, by the side of the vena portæ, at the portal fissure, and, like that vein, divides into a right and left branch for the corresponding lobes. The *hepatic veins*, which convey the blood from the liver, converge from all parts of the organ, to the notch in its posterior border, where they enter the ascending vena cava, by two or three main trunks, and thus the blood from the liver, mixed with that from the lower half of the body, ascends to the heart.

Fig. 97.

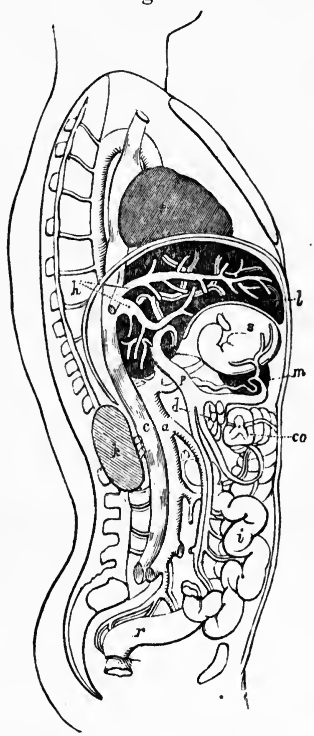


Fig. 97. Diagram to show the large vessels concerned in the so-called portal circulation. The trunk, or body, is supposed to be divided down the middle line, so as to show the cavity of the thorax or chest, above the arched diaphragm, and that of the abdomen below it. In the abdomen, *l*, is the liver; *s*, the stomach; *d*, a section of the duodenum, and pancreas; *i*, the small intestine; *co*, a part of the colon; *r*, the rectum; *m*, the lower end of the spleen; and *k*, the right kidney. The blood to all these parts, is supplied through arteries which are branches of the abdominal aorta, marked *a*. From the rectum, *r*, and the kidney, *k*, the blood is returned by veins, which end in the great ascending vein, named the ascending vena cava, marked *c*, which conveys the venous blood directly through the diaphragm, and into the right side of the heart, *o*. But the blood from the stomach, *s*; spleen, *m*; duodenum and pancreas, *d*; small intestine, *i*; and large intestine, *co* (excepting the rectum, *r*), is collected by venous branches, which end in a large venous trunk, named the vena portæ, or portal vein, *p*, by which this venous blood is conveyed to, and distributed by branches through, the liver. From this organ, it is collected by other veins, which unite to form the hepatic veins, *h*, which then join the ascending vena cava, *c*, and so reach the right side of the heart.

The liver, like all secreting glands, is provided with ducts. These, named the *hepatic ducts*, form, as they issue from the gland, two principal trunks, one from the right, the other from the left lobe. They emerge at the bottom of the portal fissure, where the two chief divisions of the portal vein and hepatic artery enter, and then unite to form a single duct, named *the hepatic duct*, *ductus choledochus*, or *bile duct*. Having descended for about two inches, this joins another duct proceeding from the gall-bladder, Fig. 96, *g*, named the *cystic duct*, and so forms the *ductus communis choledochus*, or *common bile duct*. This latter duct is about three inches long, and two or three lines wide; passing down behind the duodenum, *d*, it reaches the left or concave border of the intestine, where it comes in contact with the pancreas, and soon after, with the duct of that gland, or pancreatic duct, Fig. 88, *a*, Fig. 96. The two ducts then pass together, and obliquely, through the walls of the duodenum, for about three-quarters of an inch, and finally, opposite the junction of the middle and lower parts of the duodenum, about three inches below the pylorus, open upon a slight eminence of the mucous membrane, by a common and slightly constricted orifice, provided with a kind of sphincter. Sometimes, however, the biliary and pancreatic ducts open separately into the duodenum.

The lymphatics of the liver are either superficial or deep; the former ramify upon its surface, the latter emerge at the portal fissure. The nerves are comparatively few in number; they are derived chiefly from the sympathetic system, and, as usual with those nerves, are supported on the arteries. The pneumogastric nerves, especially the left, also supply a few branches to the liver. The right phrenic nerves send filaments to the peritoneal coat. Beneath the partial peritoneal investment, the liver possesses a proper *areolar* coat, which covers its whole surface, and, at the portal fissure, passes into the interior of the organ, and becomes continuous with a loose areolar tissue, named the *capsule of Glisson*, to be presently described.

The proper *substance* of the liver, is firm, and presents, on section, a reddish-brown mottled aspect. It is composed of a multitude of compressed polyhedral masses, about the size of a pin's head, measuring from $\frac{1}{24}$th to $\frac{1}{12}$th of an inch in diameter, named the *hepatic globules;* they cause the granular appearance of the torn surface of the liver. These little portions of gland-substance, are held together by the ultimate ramifications of the bloodvessels and ducts, and also by a fine areolar tissue, occupying the *interlobular spaces*, and named the *interlobular* tissue, which is itself connected, on the surface of the gland, with the areolar coat. The hepatic lobules are closely arranged around certain canals, which commence at the portal fissure, branch out in all directions through the gland, becoming smaller and smaller as they proceed, and ultimately lose themselves in the interlobular spaces. These are the *portal canals*, which contain not only the branches of the portal vein, but also those of the hepatic artery, and hepatic ducts, the deep lymphatics, and the nerves. Surrounding and supporting those vessels, ducts, and nerves, is found the loose areolar tissue, named Glisson's capsule, which, outside and beyond the portal canal, is continuous with the interlobular tissue. A transverse section through a portal canal, shows a roundish space in the gland-substance, occupied chiefly by a section of a portal vein, with which, however, are associated one or two branches of the hepatic artery, and hepatic duct, the whole being embedded in the capsule of Glisson; the arteries are smaller than the duct; the canal also contains lymphatics, invisible, unless injected, and nerves supported upon the arteries; in the smallest portal canals, the parts are not so distinct. The *hepatic veins* do not lie in the portal canals, but pursue a separate course through the liver, the branches of these being seen, on a section, passing along through the gland, immediately surrounded by the lobules. As the portal veins diverge from the portal fissure, whilst the hepatic veins converge to the posterior border of the gland, their branches cross each other; moreover, they have very different relations to the hepatic lobules.

Each minute lobule has one aspect, which is named its *base*, whilst its other surfaces are called its *sides*. The *bases* of all the lobules rest upon the so-called sublobular veins, which are branches of the hepatic vein, the inner surface of which, as shown when they are opened, is marked by the polygonal outlines of the bases of the lobules. When divided transversely, the lobules are polyhedral; when cut longitudinally, they present a foliated appearance, and are seen to be supported on the sublobular hepatic veins, like sessile leaves upon a leaf-stalk.

The *sides* of the lobules are turned towards each other in the interlobular spaces, towards the portal canals, or to the surface of the liver. The portal veins, ramifying in the portal canals, give off branches which enter the interlobular spaces, and are hence named *interlobular veins;* from these, still finer branches penetrate the *sides* of the lobules, and end, within them, in the so-called *lobular venous plexus*, or *lobular capillary network.* From this network proceeds a small vein, occupying the centre of each lobule, named the *intra-lobular vein*, and belonging to the hepatic venous system; it opens by a minute orifice, situated in the middle of the *base* of the lobule, into the corresponding *sublobular vein.*

It will thus be seen, that the blood of the portal vein is conveyed, by the portal interlobular veins, to the sides of the lobules, and thus reaches their internal vascular plexus, from which it is collected by the hepatic intralobular veins, and so passes out, at the bases of the lobules, into the sublobular hepatic veins, by which it is ultimately conveyed away.

From the peculiar distribution of the branches of the portal and hepatic venous systems, in each lobule, it follows that a congested state of either, influences the mottled color of the liver in a characteristic manner. Thus when the hepatic system is congested, a rather frequent occurrence, the centre of each lobule is dark, and the circumference paler; whilst in portal congestion, which is rare, and occurs chiefly in children, the centre of each lobule is pale, and the marginal part dark. From the great size of the portal vein, as compared with the hepatic artery, it is evident that the liver is chiefly supplied by venous blood. But even the arterial blood furnished to this organ, by the hepatic artery, appears to become venous and *portal*, before it reaches the plexus within the lobule. The hepatic artery is a nutrient vessel, supplying the framework, and not the secreting tissue, of the liver; its branches terminate in a capillary network, in the coats of the blood-vessels and ducts, in the areolar tissue of the capsule of Glisson, the interlobular tissue, and the areolar coat of the liver; from these parts, the blood now becomes venous, is believed to be returned into the smaller portal veins, and in this *indirect* manner only, to reach the hepatic lobules. According to this view, amongst the sources of the portal blood, must be included, not only the stomach, intestinal canal, pancreas, gall-bladder, and spleen, but also the non-secreting part of the liver itself.

The *secreting* portion of the liver is composed, in each lobule, first of the lobular capillary network or venous plexus, already mentioned, as interposed between the termination of the portal and the commencement of the hepatic venous systems; secondly, of an intermediate *gland-substance* or *parenchyma*, occupying the interstices of this capillary network; and thirdly, of the commencements of the hepatic or biliary ducts. The gland-substance consists of roundish, or flattened, polyhedral, nucleated cells, having a delicate cell-wall, one or two bright vesicular nuclei with nucleoli, and certain faintly yellowish, semifluid, amorphous, granular contents, in which are commonly found larger or smaller globules of oily matter. These very peculiar cells are named the *hepatic cells;* they vary from $\frac{1}{1030}$th to $\frac{1}{840}$th of an inch in diameter. They are the true secreting gland-cells of the liver, their contents closely resembling the bile, which is secreted by them. The relation of these cells to the finest commencements of the biliary ducts, and the mode of commencement of those ducts, are difficult points for investigation. The clusters of the hepatic cells occupy the interstices of the lobular venous plexus, and, whatever may be their relation to the finest commencements of the ducts, or in whatever mode the bile, formed within these cells, passes into the ducts, the hepatic cells themselves lie outside the venous plexus, and this has no direct communication with the ducts. The hepatic cells, moreover, are arranged in lines or rows, which radiate, amongst the bloodvessels, from the centre towards the circumference of the lobule. By most anatomists, these rows of cells are said to be supported on a thin basement-membrane, which is continuous with the walls of the commencing efferent biliary tubes or ducts, so that the liver might be regarded as a complex gland, having ramified anastomosing ducts (Beale and Retzius). According to another view, however, the hepatic cells are merely arranged around the network of the lobular plexus, and are unsupported by a proper basement-membrane (Kölliker).

The Gall-bladder.—The hepatic, cystic, and common bile ducts, already described, are composed of a strong areolar coat, containing a few muscular fibres, and lined by a mucous membrane covered with a columnar epithelium; in the finest ducts, the epithelium is squamous. The walls of these ducts present generally minute racemose mucous glands, the openings of which are arranged in rows within the ducts. The cystic duct which leads to the gall-bladder has, in its interior, a series of oblique crescentic projecting ridges or folds, following each other closely, so as to present the appearance of a spiral valve.

The *gall-bladder*, Fig. 96, *g*, is a pear-shaped sac, from 3 to 4 inches long, about 1 inch across at its widest part, and holding rather more than one fluid ounce. It is lodged in a fossa on the under surface of the liver; its larger end or *fundus*, projects beneath the anterior border of the gland; whilst its narrow end or neck, directed, beneath that organ, upwards, backwards, and to the left, is continuous with the cystic duct. Its upper surface is attached to the liver by areolar tissue and bloodvessels; the rest is covered by the peritoneum, which therefore furnishes it with a partial serous coat. Its proper walls are composed of interlacing bands of white, fibrous, and areolar tissue, intermixed with elastic fibres, and longitudinal and circular unstriped muscular fibres. Within this areolar coat is the mucous coat, which has a peculiar pitted or alveolar aspect, owing to the presence of innumerable fine ridges, which bound polygonal depressions of various size and form; at the bottom of the largest depressions there are seen, by aid of a lens, the orifices of fine recesses resembling mucous follicles. The mucous membrane of the gall-bladder is usually of a deep yellow color, and is lined by a columnar epithelium.

The gall-bladder forms a sort of receptacle, or *reservoir* for such bile as is not immediately required for the purposes of digestion. It has been shown, in animals, in which artificial openings, or fistulæ, have been made into the hepatic duct, that bile is being constantly secreted by the liver. In the intervals between the process of digestion, the secretion is slow; but, during digestion, the bile is secreted very rapidly, and at once passes along the hepatic duct, and common bile duct, into the duodenum; such bile is named *hepatic bile*. The period of most rapid secretion, in animals, has been variously stated to be from one or two hours, to ten or twelve hours after eating. According to observations made by Dalton on a dog, the quantity increases suddenly after eating, reaches its maximum in an hour, and then gradually declines; a far larger quantity enters the intestine during the first hour, than in any other equal period. Abstinence lessens the quantity very much. In the intervals between digestion, however, the bile being secreted more scantily, has not sufficient force to pass through the narrow orifice of the common duct, and thus more or less of the secretion enters the gall-bladder; there, it undergoes inspissation, losing water, and receiving much mucus from the gall-bladder, some having been already added to it, in the ducts. It thus becomes darker, and more viscid, and, in this condition, it is called *cystic bile*. The mechanical effect of the spiral folds in the cystic duct, on the passage of the bile into, or out of, the gall-bladder, is probably to favor its entrance, and somewhat check its escape. During digestion, both cystic and hepatic bile are believed to be employed, and it is supposed that, at that period, the former is pressed out of the gall-bladder, partly by the distended stomach, and partly by the contraction of its own muscular fibres, stimulated in a reflex manner, by the acid chyme passing over the orifice of the common bile duct, the sphincter-like margin of which may be at the same time relaxed.

The analyses of bile present some discrepancies, which may depend on the difference between the hepatic and the cystic bile. Speaking generally, the bile is a yellowish, or yellowish-green, viscid fluid, having a peculiar smell and a bitter taste. In carnivorous animals, its color is brownish-yellow; in herbivorous animals, it is generally greenish. The quantity of bile secreted by a man in twenty-four hours is uncertain.

In dogs, with artificial biliary fistulæ, the quantity secreted daily is about $\frac{1}{2}$ oz. to every pound weight of the animal, or $\frac{1}{32}$d part of its weight (Kölliker, H. Müller). Supposing the weight of a man to be 140 lbs., this would give 70 oz. or 4 lbs. 6 oz. avoirdupois in a day, of which about $\frac{1}{25}$th, or nearly 3 oz., would be solid matter. This estimate, however, appears very high. Bidder and Schmidt calculate the daily quantity secreted by a man to be 56 oz.; Nasse and Platner's observation on the dog, would give a total daily quantity for man of 33½ oz.; whilst others again have estimated it at only from 17 to 24 oz. The specific gravity of the cystic bile in man, varies from 1026 to 1032; that of hepatic bile is of course less. The cystic bile of man contains about 10 per cent. of solid matter; while the bile from an artificial fistula in the bile duct of an animal, *i. e.*, hepatic bile, contains from 3 to 5 per cent. only.

The analysis of cystic ox gall by Berzelius, gives the following percentage composition:

Water,		90.44
Bilin, with fat and coloring matters,	8.	
Mucus, chiefly cystic,	.3	9.56
Salts,	1.26	
		100.00

The analyses by other chemists show a similar composition, but, according to Strecker, the *bilin* of Berzelius is a compound substance. Its two characteristic constituents are the colorless conjugated fatty acids, named *glycocholic* or *cholic*, and *taurocholic;* the one formed by the combination of a nitrogenous body, named *glycocin*, or *glycocoll* and *cholalic* acid; the other, formed by the union of the same acid with another nitrogenous body, which contains sulphur, named *taurin*. The chemical relations of these substances may be seen by comparing their atomic compositions (p. 85).

Cholalic acid crystallizes in white tetrahedra; dissolved in sulphuric acid, with the addition of sugar, it yields a purple violet color, the reaction of the so-called Pettenkofer's test for bile. Glycocoll, obtainable also by the action of acids or alkalies upon glue and some other animal substances, forms hard, transparent, colorless crystals, soluble in water, but nearly insoluble in alcohol and ether. Taurin crystallizes in white hexagonal prisms, inodorous and almost tasteless; it contains the large proportion of one-fourth its weight of sulphur; it leaves much sulphurous acid on being burnt, and gives off sulphuretted hydrogen when decomposed. Both glycocoll and taurin are neutral substances having a tendency to unite with acids, to form, as in the bile, conjugated acids. Glycocholic, or cholic acid, consists of fine crystalline needles, soluble in water and alcohol, but very slightly so in ether, having a bitter sweet taste, and a strong acid reaction. Taurocholic acid has not yet been obtained in a crystalline form. In the bile, the glycocholic and taurocholic acids, which form from 4 to 7 per cent. of that secretion, are always united with soda, as glycocholate and taurocholate of soda. The bile, however, occasionally contains an excess of some base; for, though often neutral, it may be feebly alkaline. The substance of the liver has, or rapidly acquires after death, an acid reaction. The proportions of glycocholic and taurocholic acids vary in the bile of different animals, but are tolerably constant in each species. In the dog, the glycocholic acid is scanty, and sometimes absent. In the pig, another allied acid is found, named *hyocholic*, and a small quantity of an acid analogous to the taurocholic. In the goose, a different allied acid exists, named *tauro-chenolic*. Although varied in different animals, and present in variable proportions, the characteristic constituent of the bile is, in all cases, a soda salt of some fatty acid, resembling the acids of fatty and resinous bodies. The sulphuretted and nitrogenous body, taurin, is always present.

The next most characteristic constituent of the bile is its coloring matter, named by different chemists *cholepyrrhin*, *bilipyrrhin*, and *biliphæin*. This forms about 5 per cent. of the secretion. According to Berzelius two modifications of coloring matter exist in bile. The one, a *yellowish* coloring substance, was named by him *bilifulvin;* it seems to coincide with the cholepyrrhin and biliphæin of other writers. It is uncrystallizable, insoluble in water, only slightly soluble or insoluble (Brücke) in alcohol, but especially so in caustic alkalies, and in chloroform. It affords a peculiar reaction with nitric acid or nitrates, which, when added in small quantities to the yellow alkaline solution, first produce a green color, then blue, violet, and red, and finally yellow again, owing, it is supposed, to the occurrence of different degrees of oxidation. The other coloring matter of the bile, smaller in quantity, is *green*, and hence was named by Berzelius *biliverdin;* it was supposed by him, though not proved so, to be identical with chlorophyll. It is insoluble in chloroform, slightly so in alcohol, and insoluble in water; it appears to be a more highly oxidized form of bilifulvin. These coloring matters are closely allied to the hæmatin, or cruorin of the blood; but neither these, nor the fatty acids of the bile, pre-exist in the blood; they are formed in the liver by the hepatic cells.

In addition to these, its essential constituents, bile contains about 1 per cent. of ordinary fats, margarin and olein, or alkaline margarates and oleates. It also presents traces of *cholesterin*, the fatty, or resinoid body, which likewise exists in nervous substance, in the blood, and in certain diseased exudations. [Cholesterin is probably derived from the metamorphosis of nervous tissues, whence it is absorbed by the capillaries and conducted to the liver, where it is eliminated.—F. G. S.] Cholesterin crystallizes in brilliant colorless plates, insoluble in water, soluble in boiling alcohol and in ether, and absolutely resisting saponification. In the living body it is probably held in solution by fluid fats. The bile contains about 1 per cent. of salts, its ashes yielding, besides soda, in large proportion, traces of potash, magnesia, and lime, in combination with phosphoric acid and chlorine. The mucus found in bile, indicated by the presence of mucous and epithelial cells, is an adventitious substance, derived from the walls and follicles of the bile ducts, or gall-bladder.

Besides being engaged in the formation of biliary substances, partly intended for use in the digestive process, and partly destined, as we shall hereafter explain, to be thrown out of the body as excrementitious matters, the liver has recently been discovered to perform another most remarkable office in the economy, viz., that of separating from the blood by its cells, a substance named *glycogen*, or *animal starch*, which has the property of being rapidly transformed into glucose, or grape sugar. This sugar is supposed to enter the hepatic blood, to proceed with it to the heart, and thence to the lungs, to be oxidized in the respiratory process, and aid in the development of heat. This *glycogenic* or *sugar-forming* function of the liver, will be more fully noticed in the section on Secretion.

Sources and Composition of the Pancreatic Juice.

The *pancreas* (πᾶν κρέας, all flesh), or abdominal sweetbread, is a long, narrow, pinkish gland, flattened before and behind, having its right, larger end, lodged in the concavity of the duodenum; whilst its left, pointed extremity, touches the spleen. Its shape has been compared to that of a dog's tongue, or of a hammer. It crosses over the front of the first lumbar vertebra, behind the lower border of the stomach, and is held in place by its attachment to the duodenum, by its bloodvessels, nerves, lymphatics, and ducts, by areolar tissue, connecting it with adjacent parts, and by a peritoneal layer. It is about 6 or 8 inches long, $1\frac{1}{2}$ inch broad, and from $\frac{1}{2}$ an inch to 1 inch thick, being thicker at its larger end. It usually weighs between $2\frac{1}{4}$ and $3\frac{1}{2}$ oz., but sometimes as much as 6 oz.

In structure, the pancreas resembles the salivary glands, and has been termed the *abdominal* salivary gland. Its numerous lobes and lobules are compressed, and are held together by the vessels, ducts, and interlobular areolar tissue. Each lobule, like those of the parotid gland, Fig. 42, *c*, consists of a branched duct, ending in rounded vesicles, surrounded by networks of capillaries. The ducts, from the numerous lobes, join a principal duct, which runs through the gland from left to right. This duct, the *pancreatic duct*, or *canal of Wirsung*, who discovered it in the human body, in 1642, is about the size of a small quill; it emerges from the larger end of the gland, and, accompanied by the common bile duct, passes, with it, obliquely through the walls of the duodenum, and, about 3 inches below the pylorus, opens into the intestine by a common orifice with the bile duct, or sometimes by a separate aperture. Occasionally there exists a supplementary pancreatic duct, which enters the duodenum about an inch from the chief duct.

The secretion from the pancreas, or the *pancreatic juice*, is a somewhat viscid, transparent, colorless, and inodorous fluid. The quantity secreted daily, in animals, varies, according to different observers, from 15 to 35 grains per hour for each pound weight of the body; so that in a man weighing 140 pounds, the quantity secreted would be from $4\frac{3}{4}$ oz. to 11 oz. per hour. The secretion is probably not continuous, and its quantity increases as digestion goes on, the activity of the process being, by some, referred to the absorption of albuminoid substances already digested. From these fluctuations, it is impossible to estimate correctly the quantity formed daily; which has been differently estimated at from 7 oz. to 16½ lbs. Statements, almost as discrepant, have been made concerning the gastric juice and bile, correct results, as regards these internal secretions, not being so attainable as in the case of the saliva. The collection of these fluids, by aid of artificial fistulæ, in animals, is open to the objection, that the conditions, especially of the nerves, which govern the quantity of the secretion, are not healthy. The total quantity of the digestive fluids poured into the alimentary canal, after taking food, is, however, much greater than was formerly supposed, and, in comparison with the blood circulating in the body, is very great.

The solid constituents of the pancreatic juice, as estimated from cases of artificial fistulæ in animals, vary from 1.5 to 6, or even 10 per cent.; the more rapid the secretion, the less solid matter it contains. Its most peculiar constituent is an albuminoid substance named *pancreatin*, the special composition of which is not yet determined. Like salivin, this substance is soluble in water, coagulable by heat, and precipitable by alcohol, but may again be dissolved in water; unlike albumen, it is precipitated by sulphate of magnesia. To the pancreatin are attributed the peculiar digestive properties of the pancreatic juice, which differ, in one respect, most remarkably, from those of the saliva.

The pancreas, indeed, resembles the salivary glands anatomically, but not physiologically; for its secretion is much more viscid, is coagulated by strong mineral acids, and does not contain sulphocyanide of potassium. Its salts, about .5 to 1. per cent., are chiefly chloride of sodium and phosphate of lime and magnesia. Like the saliva, it is alkaline, but more strongly so; as digestion proceeds, it becomes more alkaline, but less viscid and coagulable. On standing, it speedily becomes neutral and then acid; it soon putrefies, but may be preserved for a few days, at a temperature of 45°; its properties are destroyed by a heat slightly above that of the body. It contains the débris of a few nucleated cells.

Sources and Composition of the Intestinal Juices.

The mucous membrane of the small intestine is provided with two kinds of secreting glands, named respectively, after their discoverers, the *glands of Brunner* and the *glands*, *follicles*, or *crypts of Lieberkühn*. The secreted products of all these glands, constitute the *succus entericus*.

Brunner's glands are found in the duodenum, being most abundant near the pylorus, and disappearing lower down, very few being present at the commencement of the jejunum. They are compound racemose glands, like the buccal and labial glands, and appear to bear the same relation to the pancreas as those glands do to the salivary glands. They secrete a viscid alkaline mucus.

The *follicles* or *crypts* of *Lieberkühn* are found throughout the small and large intestines. They consist of multitudes of minute tubuli, closed at their deep extremities, but opening on to the surface of the mucous membrane, perpendicularly to which they are arranged, more or less closely together. In the small intestine, they measure from $\frac{1}{80}$th to $\frac{1}{60}$th of an inch in length, and about $\frac{1}{400}$th of an inch in diameter. Their orifices are seen, Fig. 98, by aid of a lens, in all parts of the small intestine, even on the valvulæ conniventes, between the villi, and also in little circlets, around the closed sacs of the so-called agminated glands. Their total number has been estimated at several millions. They are sometimes flask-shaped, but never subdivided, like the gastric glands; they are lined with a columnar epithelium, Fig. 99, and are surrounded by capillaries.

They contain a transparent granular fluid, the *intestinal juice proper;* sometimes they are distended with opaque mucus, and desquamated epithelial cells destitute of fat. The composition of the intestinal juice is not well known; it probably differs from ordinary mucus, and has special properties; it is colorless and viscid, and is usually described as being strongly alkaline, but, according to others, it is acid in a great part of the small intestine; it contains from 2 to 3.5 per cent. of solid matter, in which is included an organic substance, precipitable by alcohol and resoluble in water, but forming insoluble precipitates with metallic salts.

Attempts have been made to collect it, from animals, by ligaturing previously emptied portions of intestine, or by forming artificial intes-

Fig. 98.

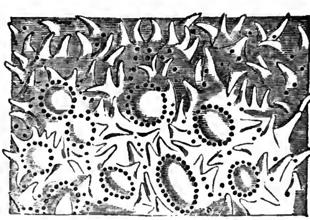


Fig. 99.

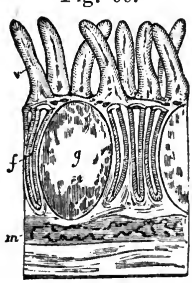


Fig. 98. Portion of the border of a Peyer's patch, magnified about twelve diameters. It shows the minute pointed processes named the villi of the small intestine, found both on the general surface, and also on the lighter part or Peyer's patch. On this latter are seen the rounded or oval sacs, constituting the agminated glands, with the villi between, not upon, them. Around the borders of these are circlets of the orifices of the intestinal tubuli, or crypts of Lieberkühn, others of which are seen, scattered over the general surface between the villi. (After Boehm.)

Fig. 99. Diagrammatic vertical section of one sac, and a part of another, from a patch of Peyer, with the surrounding parts. *g*, the sac with its granular contents. *f*, one of the intestinal tubuli, crypts, or follicles of Lieberkühn, of which three others are seen, on the other side of the sac. *v*, the intestinal villi, on the surface of the mucous membrane, covering the patch. *m*, cut ends of the circular muscular fibres; beneath these, the longitudinal fibres, and the serous or peritoneal covering of the intestine. (After Kölliker.) Magnified forty diameters.

tinal fistulæ; but the fluid so obtained must differ from the normal secretion. The quantity daily secreted in Man is uncertain, but is doubtless considerable, especially after meals.

The tubuli or crypts of Lieberkühn of the large intestine, are longer, wider, more numerous, and more closely arranged than those of the small intestine. The entire surface presents, when examined with a lens, a cribriform aspect, due to the numerous orifices, which, in the lower part of the intestine, are almost visible to the naked eye; they are lined with columnar epithelium. Besides these crypts, there are found, scattered over the mucous membrane of the large intestine, small *depressions*, resembling saccular glands; they were formerly described as *solitary glands*, but they are lined with a columnar epithelium only, and are placed over certain closed sacs, exactly similar to those of the so-called solitary glands of the stomach and small intestine, and of the agminated glands of the latter.

The intestinal juice of the large intestine resembles, so far as is known, that of the small intestine, being composed partly of mucus, but chiefly of a special secretion, which is said to be alkaline, though, in the cæcum, the intestinal contents are acid.

CHEMICAL PROCESSES OF DIGESTION—ACTION OF THE DIGESTIVE FLUIDS, WITH HEAT.

As already stated, the purpose of the digestive process in the animal economy, is the reduction of alimentary substances into a soluble and absorbable condition, a state of solution, or of exceedingly minute subdivision and suspension in a fluid, being an essential condition, antecedent to the absorption of any nutrient substance into the living tissues. Food, as we have seen, considered chemically, consists of water, alkaline and earthy salts, and certain important organic proximate constituents, which are classified into non-nitrogenous and nitrogenous substances.

Of these, the water, the natural medium of solution or suspension of the solid alimentary substances, and likewise the saline substances, both alkaline and earthy, which are mostly dissolved in it, correspond with the water which forms three-fourths of the soft tissues of the body, and with the water and salts of the blood: they are directly absorbed without any digestive change. The organic constituents, whether non-nitrogenous or nitrogenous, are some of them soluble, and some insoluble in water at the temperature of the interior of the body, viz., about 102°. The *soluble* non-nitrogenous bodies are pectin, gum, dextrin, sugars, alcohol, organic acids, and ethers. The soluble nitrogenous substances are certain forms of albumen, fibrin, casein, gelatin, and chondrin; the albuminoid principles of the digestive fluids, viz., salivin, pepsin, and pancreatin, which are probably in a state of solution in the living body; creatin and creatinin; cerebric acid; and thein, caffein, and theobromin. Many of these also are possibly directly absorbed. The *insoluble* organic constituents are the non-nitrogenous cellulose, starch, and fatty matters; and the nitrogenous solid forms of albumen, syntonin, casein, fibrin, gluten, and legumin, and the gelatin- and chondrin-yielding tissues. All these, however soft or minutely divided, must be dissolved, before they can be absorbed. They are the most abundant constituents of our food: in all kinds of bread and biscuit, in cooked potatoes, rice, sago or tapioca, the quantity of insoluble starch is greater than that of soluble starch, gum, dextrin, or sugar; in cooked meat, poultry, fish, and eggs, and also in cheese, the albuminoid constituents are all solidified; the vegetable gluten and legumin are either solid, or are coagulated by cooking; and even the fluid or finely granular casein of milk, is first precipitated or curdled in the stomach, by the action of the acid gastric juice. Indeed, undissolved, though minute, granules of amyloid, insoluble oleoid, and solidified albuminoid substances, constitute the most nutritive forms of food.

In a chemical sense, these substances are instable compounds; they have a high atomic constitution, and are easily broken up by powerful chemical agents, by elevated temperatures, fermentation, or putrefaction. Nevertheless, under ordinary circumstances, they are insoluble in water at the heat of the body, and are decomposable, or rendered soluble, only by the action of agents and temperatures, which would be destructive to living animal tissues. Thus, starch is rendered mucilaginous only at the temperature of 160°; it is changed into dextrin at a still more elevated temperature; and it is convertible into a sugar, by the highly corrosive sulphuric acid. Of the fats, margarin and stearin become fluid only at temperatures higher than that of the body, viz., 114° and 118°; none of them are easily miscible with, or can be kept suspended, in minute particles, in watery fluids; and to render any of these soluble in water, they must be saponified by the action of caustic alkalies, which are destructive to living tissues. The solid albuminoid principles, so far from being soluble even in boiling water, have their component particles knit still more firmly together, by being boiled; and putrefaction alone will dissolve them,—a condition inconsistent with their retention of nutritive properties, and, indeed, converting them into noxious products.

The *first* problem of digestion, however, is to render such substances, which, in this point of view, are *refractory*, soluble at a temperature, and by means of agents, compatible with the life and integrity of the digestive organs themselves. But, *secondly*, starch, even when dissolved, so as to form a soluble mucilage, and also albumen, when perfectly soluble, as in the white of egg, are too tenacious to pass readily through moist membranes, and belong to the so-called *colloid* bodies, which have a feeble permeating power, in comparison with the so-called *crystalloid* substances (Graham); whilst oil, likewise, passes through moist membranes only under considerable pressure. Accordingly, in the process of digestion, starch is not only dissolved, but is converted into the crystalloid, and highly permeating substance, *sugar;* albuminoid bodies are converted into a substance named *albuminose*, which, though not shown to be crystallizable, nevertheless, permeates moist membranes with great facility; whilst fatty matters are either emulsified, decomposed, or dissolved. These transmutations are daily accomplished, within the body, at its *proper temperature*, in modes at present only hypothetically explained, by the respective actions of the salivin, pepsin, pancreatin, and conjugated fatty acids, of the saliva, gastric juice, pancreas, and bile.

Action of the Saliva and other Fluids of the Mouth.

The saliva, the chief fluid poured into the mouth, acts first, by its watery basis, as a solvent, contributing thus also, to the perfection of the sense of taste. It dissolves saline substances, the organic acids, alcohols, and ethers, gum, sugar, and the soluble albuminoid and gelatinoid bodies. Secondly, and most importantly, the saliva changes the starch granules, first into dextrin, and then into soluble and crystalloid dextrose, glucose or grape-sugar, ready for absorption. Dextrin has the same atomic constitution as starch, $C_6H_{10}O_5$, whilst grape sugar, $C_6H_{12}O_6$, appears to be produced from it, by the taking up of 1 atom of water H_2O. No evolution of gas takes place, as occurs in alcoholic fermentation. The change is more rapid than fermentation. On adding some saliva to a weak solution of boiled starch, and immediately testing it with iodine, the blue color of iodide of starch fails to appear; or, on mixing saliva with a small quantity of cooked starch, already rendered blue by iodine, the color is discharged. (Vintschgau.) These facts prove that the starch is changed; its conversion into sugar is shown by examination with a polariscope, or by boiling the fluid, after adding a slightly alkaline solution of tartrate of copper, when a yellowish-red precipitate of oxide of copper is thrown down, indicating the presence of grape-sugar (Trommer's test).

The parotid saliva is, by itself, able to convert starch into sugar; that of the submaxillary and sublingual glands accomplishes the change, when combined with the mucus of the mouth, which, indeed, has, by some, been regarded as the sole agent in this transformation. A mixture of all the fluids of the mouth appears, however, to form the most active combination for this purpose. Besides the saliva and buccal fluids, the pancreatic juice possesses this property in great perfection; but the gastric juice and the bile do not. Most animal membranes also, such as the mucous membrane of the mouth, intestines, and even the bladder, particularly if they are in a state of commencing decomposition, exhibit this power.

The constituent of the saliva to which this peculiar power of transmutation is due, is the *salivin* or *ptyalin*, which is said to act catalytically, or by *presence*, or contact; for if this albuminoid substance be precipitated by alcohol, collected on a filter, and re-dissolved in water, it will still effect the transformation very rapidly, and will convert 2000 times its own weight of starch into sugar. Neither dilute *alcohol* or *acids*, nor, it is said, even a boiling heat, arrest altogether the action of salivin. Finally, although the action of saliva is more rapid and complete on cooked starch, yet grains of raw starch, masticated and mixed with saliva in the mouth, and then maintained at a temperature of 100°, at length break down, and are converted into sugar. The saliva has no specific action on gum, pectin, cellulose, or fatty matters, unless it may, to a slight degree, emulsify the latter, nor yet on albuminoid or gelatinoid substances.

Action of the Gastric Juice, and Mucus of the Stomach.

It is the gastric juice, secreted by the peptic glands, which accomplishes the act of gastric digestion; the secretion of the racemose glands, lined with columnar epithelium, found near the pyloric end of the stomach, is supposed not to participate in this office, but it may act in the further conversion of starch into sugar. In this stage of digestion, albuminoid and gelatinoid substances are specially acted upon, and are reduced to a pulpy mixture, containing the so-called *albuminose* or *peptone*. The solid or insoluble forms, such as coagulated albumen, syntonin, and fibrin, are slowly dissolved: certain of the soluble forms, as the casein in milk, and the albumen in vegetable juices, are first precipitated, and then dissolved; whereas fluid albumen, as the raw white of egg, remains in solution whilst it is being converted into albuminose. Albuminose resembles the albuminoid bodies in chemical composition, though differences will probably hereafter be detected in it. Whatever the peculiarity of the albuminoid body, whether it be albumen, syntonin, fibrin, or casein, gluten, or legumin, it is transformed into an almost identical albuminose. Moreover, this albuminose, or peptone, possesses properties which distinguish it from the albuminoids. Thus, it is no longer coagulable by heat, nor by the action of nitric acid, though still precipitable by tannic acid, metallic salts, and strong alcohol; it is soluble in all proportions in water, so much so, that the act of digestion of the albuminoids, or their conversion into albuminose, has been referred hypothetically to a kind of hydration of the albuminoids, or a taking up by them of certain atoms of water, just as the hydration of starch or dextrin appears to be a step in their conversion into sugar. Gelatin, and the gelatin-yielding tissues, furnish a special kind of peptone, a viscid fluid, which does not, according to some, gelatinize or stiffen in the cold. The transformation of albuminoid and gelatinoid substances into the ultimate albumen and gelatin peptones, is not sudden, but is characterized by intermediate stages, in which less soluble forms of these substances appear, named *parapeptones*. Parapeptone is precipitated, in the form of flocculi, from the peptones, when their mixed acid solution is neutralized by an alkali; it is insoluble in water, though gradually dissolved by weak acid and alkaline solutions. The peptone, as already said, is highly soluble in water, and precipitable by tannic acid, alcohol, and metallic salts. When a solution of peptone is injected into the blood of an animal, it does not appear in the renal excretion; but when albumen, dissolved in very weak hydrochloric acid, is employed in a similar manner, albumen is found in the urine. These facts indicate that a true metamorphosis is effected in the albuminoid constituents of food. The peptone ultimately produced, is not only freely soluble in water, but most readily permeates moist animal membranes, and hence is a substance admirably fitted for absorption.

The gastric juice has no peptic action upon either the amylaceous or oleaginous constituents of food.

[The experiments by the editor upon Alexis St. Martin, referred to in the note on page 529, confirm the statements here made as to the office of the gastric juice in digesting albuminous articles of food, by a previous conversion into albuminose or peptones. So, also, that gastric juice has no effect upon oleaginous food other than to liberate the oil by dissolving away the albuminous envelopes of the fat-vesicles.

With regard to amylaceous constituents of food, these experiments upon St. Martin, as well as others more recently performed through the kindness of Dr. E. Brown-Séquard, who, it will be remembered, has the faculty of vomiting at will, showed distinctly the presence of grape-sugar in the products of gastric digestion, as determined by Trommer's test; and this in much larger quantity than could be obtained by the action of saliva for the same length of time upon a portion of the same arrowroot swallowed by Brown-Séquard, and which had been previously tested for glucose without the response usual when this substance is present. That the glucose thus found in the products of gastric digestion is the result of the action of *gastric* juice upon the amylaceous food is not contended for. The change has been most probably produced by the action of the mucus secreted by the mucous follicles of the stomach, as it is well known that mucus from any mucous membrane has this effect. Thus, an injection of starch in the rectum, when evacuated, is found to respond to Trommer's test for grape-sugar. (*North American Med.-Chir. Rev.*, July, 1857, and *Jour. de Physiologie*, Jan. 1858.) F. G. S.]

The agent by which the gastric juice dissolves, or excites the solution of albuminoid and gelatinoid substances, is the peculiar animal substance, itself albuminoid, the *pepsin;* but the free acid contained in it is also essential to the digestive process. Dilute hydrochloric, or other acid, of the strength of that present in the gastric juice, possesses by itself no digestive property, though it renders the tissues semi-transparent, and dissolves out earthy matter from bones. Again, pepsin alone, obtained pure by precipitation from the gastric juice by means of alcohol, filtration, and re-solution in water, also possesses no digestive power; nor does pure gastric juice, provided that its acid be carefully neutralized; for small pieces of meat, or albumen, placed in such solutions, do not digest, but after a time putrefy.

These, and many other facts, concerning the rapidity and results of digestion, have been established by experiments, amongst the most interesting in Physiology, on *artificial digestion*, *i. e.*, by subjecting different substances to the action of different digestive fluids, under exactly like conditions. The temperature employed may vary from 96° to 102°. During natural digestion, the temperature of the stomach of Alexis St. Martin, was found to be from 100° to 101° F.; whilst during fasting, it was 98° or 99°. (Dr. F. G. Smith.)

An artificial digestive fluid may be obtained directly from the human or animal stomach, by first exciting the flow of gastric juice, and then causing vomiting; or it may be collected from artificial gastric fistulæ in animals. A digestive fluid may, however, be more conveniently, and less cruelly, obtained from the gastric mucous membrane of the recently killed sheep, calf, ox, or pig, especially if the animal be slaughtered whilst digestion is going on in the stomach. Finely cut portions, or scrapings of the mucous membrane, are to be macerated in 20 times their weight of *cold* water for 24 hours, with frequent agitation of the mixture. A temperature as low as 50° is desirable, to prevent the pepsin, extracted from the membrane, from exhausting itself, more or less, in the digestion of that membrane itself. The fragments of the mucous membrane being allowed to subside, the supernatant fluid is poured off, forming a solution of pepsin extracted from the peptic cells, but containing only a slight and insufficient quantity of free acid; for the pepsin is stored up in the peptic cells, so that it may be extracted by water after death, whilst the acid of the gastric juice is probably secreted only when required, perhaps by the columnar epithelial cells; it therefore ceases on the death of the animal. Hence the solution of pepsin as above prepared, requires an addition of hydrochloric acid to make it digest actively. Too little, or too much, acid diminishes its peptic properties. Ten minims, *i. e.*, about 13 drops of the pure hydrochloric acid of commerce, to every ounce of the digestive fluid, is said to be the best proportion.

The inefficiency of the acid, and of the solution of pepsin, separately employed, and the powerful effect of the two together, may be thus strikingly illustrated. Three fluids are to be prepared, one, of hydrochloric acid and water, in the proportion of 13 drops to the ounce; a second, of the above described solution of pepsin, exactly neutralized by carbonate of soda; and a third, of the same solution, acidified with hydrochloric acid, in the proper proportions. In equal quantities of these fluids contained in glass jars of the same size, are suspended the legs of fowls, or the fore-limbs of rabbits, either cooked or uncooked, one in each jar; the jars are then placed in a water-bath, and maintained at a temperature ranging between 96° and 102°, for 24 hours. At the end of that period, the limb suspended in the hydrochloric acid and water, is found to be slightly swollen, pale and semi-transparent, whilst the solution, itself of a yellowish-tint, is quite clear, and free from deposit. The limb submitted to the action of the neutralized solution of pepsin, which is itself slightly turbid, appears sodden, but its surface is nowhere dissolved; the fluid itself is darker, but not more turbid. In the acid solution of pepsin, however, all the soft parts of the digested limb are, *as it were*, *eaten away* and *pulpified*, or dissolved; the tendons disappear first, then the muscles, next the ligaments, and lastly, even the bones and cartilages are more or less attacked, the slight residual mass contrasting strongly with the undissolved and swollen limbs in the other two solutions; moreover the fluid itself has a brownish color, and presents a soft flocculent or pulpy grumous sediment, several inches deep, which, on the slightest agitation, mixes easily with the fluid above, and resembles the digested contents of the stomach, after taking animal food.

Phosphoric, sulphuric, and even nitric acid may be employed in the artificial digestive fluid, but they are not so suitable as hydrochloric. Very strong acids, metallic salts, caustic alkalies, alum, tannin, and strong alcohol, destroy its digestive properties, and so does a temperature of 120° A strongly acid artificial gastric juice is better suited for the digestion of some substances, such as coagulated albumen, the solid syntonin of cooked muscle, and legumin; whilst fibrin is more quickly dissolved in a feebly acid juice, even 1 drop to 1 oz. of fluid. (Brücke.) The strongly acid natural gastric juice of the Carnivora acts most quickly on the firmer animal albumen, but the less acid secretion of the Herbivora, most quickly on the softer vegetable gluten. The human gastric juice has a feebler power even than that of the herbivora; its acidity declares itself immediately on the introduction of food into the stomach, and increases, for a time, as digestion goes on, when the less digestible food requires to be attacked; when the stomach is empty, the acidity quite disappears.

The power of the gastric juice to dissolve animal substances is well illustrated by the softening or digestion of the coats of the stomach by its own secretion, after death, often noticed both in men and animals dying whilst digestion is going on: all the coats of the stomach may be thus perforated; in the human body, the effects may simulate the action of a corrosive poison.

The immunity of the living gastric mucous membrane, or its power of resisting the solvent action of its own secretion, has been variously explained. According to one view, the epithelium and mucus constitute a sufficient protection; for when the former is detached, the subjacent tissue is said to be attacked, in the living stomach, as well as after death. The "vitality" of the mucous membrane (the sum of its vital actions), has been supposed to enable it to resist solution; and this resistance necessarily ceases on the death of the part. A more recent view, founded on many experiments, attributes the non-solution of the living mucous membrane, to the protecting influence of the blood in the capillaries, which is supposed to maintain, so long as the circulation continues, the alkalinity of the tissues, a chemical condition incompatible, as we have seen, with peptic digestion. (Pavy.)

The digestive action of the fluids of the living stomach was shown long ago by Spallanzani, Stevens, Tiedemann, Gmelin, and others, who induced dogs to swallow pieces of sponge fastened to strings, and afterwards withdrawing them, obtained a quantity of fresh gastric juice, which slowly dissolved food kept in it at a temperature of 100°. But the most direct evidence of the solvent power of gastric juice, is that obtained by Dr. Beaumont, who employed the fluid collected from the stomach of the Canadian voyageur, Alexis St. Martin. With that fluid, the process of solution was very rapid. Three drachms of boiled beef placed in an ounce of fluid, maintained at a temperature of 100°, began to digest in 40 minutes; in 60 minutes a pulpy deposit began to form; in 2 hours, the areolar tissue was digested, leaving the muscular fibres disconnected or loosened; in 6 hours, these were nearly all digested; and in 10 hours, the meat was completely dissolved; the gastric juice, from being transparent, was now the color of whey, and contained a meat-colored sediment. Digestion was still more rapidly accomplished, when a similar piece of beef, attached to a thread, was placed in Alexis St. Martin's stomach; for, although at the end of one hour, its condition appeared much the same as that of the piece of beef digested in the gastric fluid out of the body, at the expiration of two hours, it was completely dissolved.

From these and other experiments, it is evident, that, with the exception of the rapidity of the two processes, artificial and natural digestion are identical in character. The rapidity of natural, as compared with artificial digestion, may probably be explained, partly by the more powerful action of a continuously fresh supply of gastric juice, and partly by the constant removal of the outer pulpified layer of the nutrient mass, by the incessant pressure and motion of this mass by means of the muscular coats of the stomach. Artificial digestion is much accelerated by occasional agitation.

The mere quantity of fluid employed in natural digestion must also be very important. It has been shown, from experiments on the gastric juice of the dog, that 20 oz. of fluid are needed for the digestion of 1 oz. of albumen. The daily quantity of gastric juice secreted by a man, 140 lbs. in weight, has been estimated at 14 lbs. or 11 pints imperial. A pint of saliva, which is a moderate estimate, and 2 pints of water consumed as beverage, would make a total of 14 pints of fluid, employed in the gastric digestion of the daily solid food; beyond the stomach, 2½ pints of bile, 1½ pint of pancreatic juice, and 1 pint of intestinal juice are added. The total quantity of fluid employed in the digestive process in 24 hours, certainly exceeds the quantity of blood in the body, which, taken at $\frac{1}{13}$th part of the weight of the latter, would be, for a man weighing 140 lbs., less than 11 lbs. or 9 pints. It is evident, therefore, that the large quantities of fluid daily secreted for the purposes of digestion, can only be supplied by a circular movement of the same aqueous particles, in successive acts of secretion, absorption, re-secretion, and re-absorption. The water which leaves the blood to form part of the digestive juices, re-enters the blood with the absorbed food, once more leaves it in the newly formed digestive juices, and is again re-absorbed, until digestion is complete. This continued irrigation of the food, combined with the activity of the freshly formed gastric juice, must greatly contribute to the rapidity of natural digestion.

That the pepsin of the gastric juice is the special agent in the gastric digestion of albuminoid and gelatinoid substances, is easily shown. By evaporating the natural gastric juice, or the artificial solution of pepsin, to a viscid consistence, and adding strong alcohol to it, the pepsin is precipitated in whitish flocculi, which may then be separated by filtration, from the other constituents of the gastric juice, dried at a low temperature, and preserved for months. The dried pepsin thus obtained, forms a firm, grayish mass, or powder; it is easily soluble in, or miscible with, water, and 1 grain dissolved in so large a quantity as 60,000 grains, *i. e.* 6¼ pints of ascidified water, still possesses digestive properties. Pepsin, whether dry or dissolved, as in natural or artificial gastric juice, loses its digestive power, if it be subjected to a temperature a little above that of the body, for example, a heat even of 120°. It is likewise rendered inactive by strong chemical reagents. It is remarkable that alcohol, which precipitates it, and temporarily suspends its digestive properties, does not destroy them; for on sufficient dilution with water, it is redissolved, and again becomes active. The energy of pepsin, like that of salivin, in converting starch into sugar, is catalytic. The action of contact or pressure, exhibited by both these substances, differs from that of the yeast ferment in the alcoholic fermentations, in not causing the evolution of any gas, and in not being continually reproduced. It is said, however, by some, that the pepsin does not itself undergo waste in the process of digestion; but the power of a given quantity is certainly limited. Salivin and pepsin have been regarded as albuminoid bodies in *a state of change*, and capable of inducing changes in other albuminoids with which they are brought into contact. Putrescent albuminoid substances, as is well known, can propagate putrescent changes to fresh albuminoid substances, and can also convert starch into sugar, or one form of sugar into another. But pepsin is not a putrescent body, nor is the peptone, produced by its action on albumen, putrefied. On the contrary, it has been shown by experiment, that fresh gastric juice, applied to putrid meat, first arrests putrefaction, removing its signs, and then digests the meat. Like fermentation and putrefaction, however, digestion is retarded by low temperatures, altogether arrested at a temperature of 34°, and is stopped by high temperatures, by the action of absolute alcohol, strong acids, alkalies, and metallic salts.

The action of the gastric juice varies, according to the character of the food, its state of comminution or subdivision, and its condition of dryness or moisture. In order to determine the time required for the solution of different nutritive substances, these have been introduced, inclosed in perforated tubes of metal or glass, into the stomachs of animals, and then have been withdrawn; or, animals have been fed with such substances, and afterwards killed at certain intervals. The most important observations, however, are those made by Dr. Beaumont in the human subject. In the stomach of Alexis St. Martin, a mixed meal of animal and vegetable food was nearly all dissolved into a pulp, within an hour; and the stomach was completely emptied in 2½ hours. A breakfast, consisting of three hard boiled eggs, some pancakes with coffee, being taken at 8 o'clock, the stomach was empty at 10.15. Two roasted eggs and three apples, eaten at 11 o'clock on the same day, had disappeared at 12.15. Roast pig and vegetables, afterwards eaten at 2 P.M., were half dissolved at 3, and had disappeared at 4.30. It was further observed, that a meal, consisting of boiled dried cod-fish, potatoes, parsnips, bread and butter, eaten at 3 o'clock, was about half digested at 3.30, the bread and parsnips having disappeared, the fish being separated into threads, and the potatoes being least altered; at 4 o'clock, very few pieces of the fibre of the fish were found, but some of the potato was still perceptible; at 4.30 all was completely pulpified; and at 5 o'clock, the stomach was empty. Again it was found that rice and tripe were digested in 1 hour; that eggs, salmon, trout, apples, and venison, took 1½ hour; tapioca, barley, milk, liver, and fish, 2 hours; turkey, lamb, potatoes, pork, 2½ hours; beef, mutton and poultry, from 3 to 3½ hours; and veal a little longer. The order in which each separate article of food is mentioned above, indicates its relative digestibility, at least in the stomach of Alexis St. Martin.

As a rule, animal substances are more rapidly digested than vegetable substances. The rate of digestion of different substances corresponds with the relative necessity for their being acted on by the gastric juice. Thus, those which require the most digestion by that fluid, necessarily remain the longest, whilst those which are merely liberated, but are not dissolved in it, pass out sooner; and fluids, with their soluble ingredients, disappear the most quickly. In cases of fistulous openings in the dog, and in Man, it has been found that fibrin is digested in half an hour, casein in $1\frac{1}{2}$ hour, gelatin in 2 hours, coagulated albumen in 6 hours, and tendons in 10 hours.

During gastric digestion, the muscular tissue breaks up first into its fasciculi, and then into fibres, the striæ of which gradually disappear, the sarcolemma, as well as its sarcous contents, being dissolved; fragments of the fibres, however, pass into the intestine, and there undergo further, though, it may be, incomplete, digestion. Yellow elastic tissue appears to resist the action of the gastric juice; tendinous fibres dissolve slowly; white areolar fibres are totally dissolved. The corpuscles of cartilage are not digested, but the intercellular substance undergoes solution. The areolar fibres of adipose tissue disappear, and frequently also the walls of the fat-cells; but their fatty contents are commonly said to resist the action of the gastric juice; fat, however, may begin to be broken up into the fatty acids. (Marcet.) Of vegetable tissues, the cellulose or lignin of the cell-walls, including the dotted, annular, and spiral ducts, for the most part resist the action of the gastric fluid, which is also inoperative upon starch grains, though it does not interfere with, or totally arrest the action of the swallowed saliva, and of the mucus of the stomach upon starch. Chlorophyll, the green coloring matter of plants, appears to resist digestion; but the pectinous and albuminoid contents of vegetable cells, are completely dissolved.

Chymification and Chyme.

The general product of digestion in the stomach, resulting from the combined admixture with the food, and the action upon it, of the saliva, the mucus of the mouth and stomach, and the gastric juice itself, is called the *chyme;* the process of its formation is named *chymification.* The chyme is a thick, pulpy, grumous fluid, containing the food thus far digested, together with partially digested and indigestible matters; it has a strong sour smell and taste, and an acid reaction. The degree of acidity of the chyme varies, however, according to the quantity of acid, such as lactic or acetic acid, in the food, and also according to the relative quantities of saliva and gastric juice contained in it, much gastric juice rendering it more acid, and an excess of saliva less so. The color of the chyme depends on the food, being whitish in an infant fed on milk and farinaceous food, but of a brownish hue when meat is eaten, or greenish after vegetable diet; sometimes, also, it is tinged with bile, which has ascended into the stomach. The presence of saliva, mucus, and gastric juice, is indicated by characteristic microscopic nucleated cells. The composition of chyme, like its color, also varies with the nature of the food. With ordinary diet, it consists of a mixture of the saline, amylaceous, saccharine, albuminoid, gelatinoid, and fatty matters of the food, in different conditions of conversion or solution. The starch, partly changed into dextrin and sugar in the mouth, continues to undergo transformation in the stomach, even more rapidly, because the vegetable cells are loosened or dissolved, so as to set free the starch grains. The conversion of starch into sugar in the stomach is due to the saliva swallowed with it, for, in an animal, ligature of the œsophagus, which prevents the continued entrance of saliva into the stomach, arrests this transformation. A good deal of starch always passes from the stomach, undissolved. The albuminoid and gelatinoid substances are represented in the chyme by albuminose or the albumen and gelatin peptones; whilst the fatty matters of animal tissues, perhaps to a small extent decomposed, are loosened from the fat-cells, and as well as the fatty matter of butter or cheese, are reduced to minute particles, intermixed with the rest of the chyme.

The characters of the chyme depend, however, not only on solvent actions, but also on the process of *absorption*, which begins in the stomach as soon as that organ contains fluid or dissolved matters. Owing to the escape of chyme into the intestine, the quantity actually in the stomach, at any one time, is small; and, owing to absorption, the quantity which passes into the duodenum is much less than the quantity of fluid swallowed and secreted for the purposes of gastric digestion. Even the soluble constituents of the chyme are constantly being removed by absorption. The soluble constituents of our solid and fluid food, such as saline matter, sugar, alcohol, and thein, and also the soluble products of digestion, such as sugar, and the albumen and gelatin peptones, mixed with some salivin and pepsin, are greedily absorbed, with the water of the chyme, by the *bloodvessels* of the mucous membrane of the stomach, and are then conveyed through the portal vein, into the liver.

The chyme itself, therefore, at any one moment, does not represent the simple product of the digestion of food, but the joint product of the double process of digestion and absorption. In comparison with the food taken, it necessarily contains a larger proportion of fatty matter than of saline, saccharine, amylaceous, albuminoid, or gelatinoid substances; for the fatty substances have undergone little or no chemical change, and no absorption from the stomach, whereas the others have been more or less dissolved, altered, and absorbed.

The semifluid product is, moreover, constantly being forced forwards, drop by drop, through the pyloris into the duodenum, where it undergoes further changes, now to be considered.

Action of the Bile.

The bile performs a most important part in the intestinal digestive process; but its action does not depend on the presence of an albuminoid substance, like salivin, pepsin, or pancreatin. Its importance is shown by its highly complex composition, and by its containing substances which, unlike the urea and uric acid of the renal excretion, do not pre-exist in the blood, but are formed in the hepatic cells. Secondly, the bile, as already stated (p. 538), is much more abundantly secreted during the process of digestion than at any other period; and although this may be due to the accompanying activity of the portal circulation, yet the general adaptation of means to ends in the animal economy, suggests the conclusion that the secretion is most required at that particular time. Lastly, the situation at which the bile is discharged into the alimentary canal, immediately below the stomach, and therefore very high up in the intestine, seems to indicate its special adaptation to the further digestion of some important constituent of the chyme. Nevertheless, as we shall hereafter see, a large portion of the solid constituents of the bile is removed from the body, and this fluid must, to a great extent, be regarded as an excrementitious fluid, serving to eliminate carbon, hydrogen, and sulphur. The bile also serves certain supplementary non-chemical uses. Thus, it excites the mucous membrane of the intestine, and so probably causes an increased secretion of mucus and intestinal juice. It moreover stimulates, either directly or through the nerves, the contractile fibre-cells of the mucous membrane and its villi, as well as those of the muscular coat of the intestine; the former action, probably, promotes absorption by the villi; whilst the latter excites the intestinal peristaltic action, and so aids in the onward movement of the intestinal contents. It is well known that a scanty supply of bile may lead to constipation, whilst an excess of that fluid induces diarrhœa: hence, it may be inferred, that a proper quantity helps to maintain the healthy action of the intestines. The inspissated bile of the ox is used as an aperient medicine.

As regards the chemical action of the bile, experiments, made outside the body, by digesting various constituents of food in that fluid, at a temperature of 100°, show that it has an exceedingly feeble action in changing starch into sugar; cane sugar is slowly converted by it into lactic acid; it neither dissolves albuminoid substances, nor saponifies or dissolves fat. Albuminoid and gelatinoid bodies, although stained, are otherwise unaltered; fatty matters, agitated with bile, form an imperfect opaque emulsion, but after a time, if left undisturbed, separate themselves entirely from that fluid, unchanged. Bile is said to arrest the actions of saliva and gastric juice, even when these have already commenced, upon starch and albuminoid substances. Indeed, the bile and the gastric juice decompose each other, when mixed out of the body; but this does not seem to be the case when the gastric juice is already combined with peptone. In living animals, in which biliary fistulæ have been established, so that the bile, prevented from entering the intestinal canal, escapes at the surface of the body, amylaceous, albuminoid, and gelatinoid substances are still completely digested. With regard to fatty matters, however, the bile appears in some way to assist in, or to determine, their absorption. It has been assumed that the bile is a saponaceous compound, and that it dissolves fatty matters directly, like an ordinary soap; but soaps contain more or less free alkali, which assists in dissolving additional fat, whilst the alkaline reaction of bile, even when present, depends probably on phosphate of soda. Experiment shows, however, that the bile is highly important for the proper digestion of fatty matters. In animals with biliary fistulæ, the chyle collected from the lacteals, or absorbents of the intestines, contains but a small quantity of fat: half, or even more, of the fat taken with their food, passes unchanged from the alimentary canal; and, as a consequence of this, the bodies of such animals are very lean. According to the observations of Blondlot and others, animals thus treated may live even as long as five years. Again, after ligature of the biliary duct in an animal, which prevents the descent of bile into the intestine, the fluid in the lacteals is clear and deficient in fat, instead of presenting its characteristic milky-white color, and fatty molecular contents. In what mode the bile contributes to the absorption of fat, is not yet known. It certainly does not appear to act chemically, by decomposing or dissolving neutral fats; nor does it make, with oily matters, a permanent emulsion. It probably co-operates with the pancreatic juice. It has also been shown that fatty matters permeate moist animal membranes more readily than usual, if they be first wetted with bile, or with an alkaline solution. Since provision is made in the saliva and gastric juice, for the complete digestion of amyloid, gelatinoid, and albuminoid substances, and, as we shall presently show, in describing the action of the pancreatic juice, of fatty matters also, the bile may be supposed to possess no exclusive digestive power, but rather to be superadded, in order to complete some particular part of the digestive process.

As the contents of the upper part of the duodenum, like those of the stomach, are strongly acid, whilst those of the small intestine generally, become gradually alkaline in their descent, it was formerly thought the bile, then regarded as a very alkaline fluid, was concerned in neutralizing the acid of the chyme; but it is now known that the bile is but feebly alkaline, or sometimes even neutral, and the alkalinity gradually acquired by the contents of the small intestine, is attributed partly to the pancreatic and intestinal juices, and partly to the evolution of ammonia, from slow decomposition.

The bile not only imparts a bright yellow color to the chyme in the duodenum, but it further appears to exercise an anti-putrescent action, thus preventing, or retarding, a fetid decomposition of the contents of the intestine; for, in the absence of bile from the alimentary canal, these frequently become decomposed, causing flatulence and diarrhœa. In experiments made with bile, out of the body, it is found that various fermenting processes are arrested by that fluid.

The coloring matter, with the cholesterin, and a certain portion of the other constituents of the bile, are found, more or less altered, in the residue of digestion; but by far the larger portion of its characteristic, conjugated glycocholic and taurocholic acids, is absorbed by the mucous membrane of the intestine. These acids, when boiled with hydrochloric or other acids, are decomposed into cholalic acid, on the one hand, and glycocoll and taurin, on the other. The cholalic acid is then changed into choloidinic acid, and this again into a resinoid substance, soluble in ether, but insoluble in water, called *dyslysin*. These decompositions, due, anatomically, to loss of certain atoms of water, are shown below:

Cholalic acid, ...	$C_{24}H_{40}O_5$
Choloidinic acid, and 1 water, ...	$C_{24}H_{38}O_4 + H_2O$
Dyslysin, and 2 water, ...	$C_{24}H_{36}O_3 + H_4O_2$

Similar decompositions appear to occur in the living body; for, in the small intestine, the acids of the bile are set free from their soda salts, by the hydrochloric and other acids in the chyme. At the commencement of the ileum, they are already half decomposed, and partially absorbed; at the end of the ileum, they are wholly decomposed; whilst, in the contents of the large intestine, only dyslysin is present.

[Dr. Samuel Fenwick, in his recent volume on Morbid States of the Stomach and Duodenum, says, that whatever effects the secretion of the pancreas may have upon fat, "it is not the only, nor indeed the chief agent in fitting it for absorption." This view is based upon the experiments of Bidder and Schmidt, who tied the pancreatic duct in animals afterwards fed with food containing fat, and found, some hours after the animals were killed, the lacteals distended with white chyle, exactly as in the ordinary process of digestion. Dr. Fenwick further states, "there can be little doubt that the bile is the chief agent in the digestion of fat." The fact that when fat is digested with bile at 100°, even for many hours, only a small quantity is dissolved, is not considered by him a valid objection, for the experiments of Bidder and Schmidt upon living animals give a different result. They fed a healthy dog with a carefully ascertained amount of fat. By examination of its fæces, it was found to have absorbed 11.1 grammes for each kilogramme of its weight. Another dog, in which a biliary fistula had been established, was similarly fed, the animal was allowed to lick some of the bile from the wound, and it was proved that but 2.24 grammes of fat had been absorbed for each kilogramme of weight. In a third, in which all access of bile to the intestine had been cut off, only 1.56 gramme was absorbed. Dr. Fenwick considers it evident, from these facts, that the bile is the main agent by which the absorption of fatty matters is promoted.

Further evidence is also afforded, according to the same author, by the condition of dogs in which biliary fistulæ have been produced. They are found, invariably, to lose weight rapidly, and the appetite becomes voracious; nature, by demanding an excessive supply of nutriment attempting to compensate for the waste of food caused by the diminution of fat.

Wistinghausen's recent experiments are also quoted with the same view. This experimenter has shown that oil will rise many times higher in a capillary tube wet with a solution of glycocholate and taurocholate of soda than in a similar tube moistened with water; also that it passes through animal membranes more rapidly when moistened with bile, than with water. F. G. S.]

Action of the Pancreatic Juice.

The *pancreatic juice*, or so-called abdominal saliva, possesses, like that fluid, in a remarkable degree, the power of converting starch into dextrin and grape sugar. The fresh juice is capable of so converting more than four times its weight of starch; the substance of the gland, macerated in water, also exhibits this power. Hence, probably, it aids in the metamorphosis of the starch which has escaped the action of the saliva. This, however, is a secondary use of the pancreatic fluid; for the mucus of the stomach and intestine, and the intestinal juice, also subserve this purpose; moreover, the pancreas is as large in carnivorous mammalia, the natural food of which contains no starchy matter, as it is in the herbivorous species.

The action of the pancreatic juice on gelatinoid substances has not been specially studied; but opinions differ as to its power over albuminoid bodies. It is by most authorities maintained that it does not digest these substances, because it does not dissolve them in experiments out of the body. When the pancreatic juice, or the infusion of the gland-substance employed, has undergone a kind of putrefaction, such solution may occur; but this is a condition not present in the living body. Moreover, any albuminoid substances macerated in water, will putrefy and slowly dissolve, and such putrefied soluble matter rapidly sets up similar changes in fresh albuminoid substances. Corvisart and Meissner believe, however, that the pancreatic juice is able to peptonize albuminoid substances, but that it only possesses this property when they have been previously mixed with gastric juice and bile, or when they are slightly acidified; or, as Bernard supposes, only after a certain quantity of the digested food has already passed into the circulation, so as to supply the blood with materials suitable for the secretion of some special product, needed for a very powerful pancreatic juice.

Extirpation of the pancreas affords no certain information concerning the use of its secretion. According to some, the removal of the gland is followed by the absence of white chyle in the lacteals, and the presence of undigested fat in the contents of the large intestine; at the same time, emaciation occurs. According to others, when this gland is extirpated, neither a total arrest of nutrition, nor death by starvation, necessarily follow, every constituent of the food still undergoing more or less perfect digestion, the office of the pancreatic juice being fulfilled by other secretions. Complete degeneration of the pancreas in Man, the liver and other organs remaining healthy, does not necessarily interfere with the digestive process; but, in certain diseases of this gland, fatty matter has been observed to pass undigested through the alimentary canal. The use of the pancreatic juice seems, indeed, to be subsidiary, or complementary, to the other digestive fluids; for it aids the saliva in the converson of starch into sugar. It is said by some to be able, with the gastric juice, to dissolve albuminoid matters, and if, as is generally believed, its chief office is to digest fatty matters, it must co-operate, in some manner, with the bile.

The effects of the pancreatic juice on fatty matters have been shown by experiments out of the body, and by observations on living animals. If either the fluid obtained fresh from pancreatic fistulæ in animals, or a watery infusion of the substance of the gland just taken from an animal killed during the digestive process, be agitated with a neutral fat, and the mixture be maintained at a temperature of 100°, the fatty substance is most perfectly emulsified, the action being much more complete and durable than if saliva, bile, intestinal juice, or any other animal fluid, had been employed. The emulsion lasts as long as eighteen hours, after which the fat separates. It is found, however, that a portion of the olein, margarin, and stearin, is now decomposed, having been rapidly separated into the corresponding fatty acids and glycerin. These effects are most marked when the pancreatic juice is collected a short time after digestion has begun, all the characters of the secretion being then most evident.

This remarkable decomposition is usually attributed to the pancreatin, combined with the operation of the free alkali of the fluid, just as pepsin with an acid, effects the transformation of albuminoid substances. The pancreatic juice no longer possesses this power of decomposing neutral fats into their fatty acids and glycerin, in the presence of ordinary acids, which destroy its alkalinity; hence it has been urged, that the acidity of the chyme must prevent this peculiar decomposition. But the pancreatic fluid and the intestinal juice are strongly alkaline, and moreover, the bile may here interpose, and, by means of the soda present in combination with its conjugated acids, may neutralize the acids of the chyme, and so permit the decomposition of the neutral fats of the food by pancreatic juice; for this process may not be interfered with by the acids of the bile, which are themselves fatty. That the action of the pancreatic juice is, in some important way, aided by the bile, and conversely, that the action of the bile is seconded by that of the pancreatic juice, is highly probable, from the fact that they are discharged into the intestinal canal so near together, generally, indeed, at a common orifice.

It happens, however, that in the rabbit, the chief pancreatic duct enters the small intestine rather more than twelve inches below the bile duct, which opens as usual a little below the pylorus; another smaller duct also exists, but it is almost impermeable. This arrangement has been taken advantage of, in physiological experiments on the use of the pancreatic fluid. The most interesting and important of these, is one originally performed by Bernard, and since repeated by others. A rabbit is crammed with fat, or its stomach is injected with oily matter, and it is afterwards killed, whilst digestion is going on; it is then found that the fatty matters in the intestine, above the entrance of the pancreatic duct, though mixed with the bile, are yet unchanged; whilst below that point they begin to be emulsified; moreover, the lacteals, or absorbent vessels of the intestine, above the point of entrance of the pancreatic duct, although bile is there mixed with the food, are filled only with a clear transparent fluid, and, indeed, are mostly invisible; whilst, at a point immediately below the entrance of the pancreatic duct, those vessels are charged with their characteristic milk-white fluid, containing fatty particles. To this apparently precise and unexceptionable experiment, it has been objected, by those who dispute the influence of the pancreatic juice in the digestion of fatty matters, that the difference in the contents of the lacteals, above and below the entrance of the pancreatic duct, depends upon the time that has elapsed before the animal is killed after being fed with fat. When this is done within two hours, it is said that the lacteals given off above the pancreatic duct are found filled with white chyle; but if the animal be killed from four to six hours after, the lacteals below the pancreatic duct are alone filled. These results are not in accordance with the experience of most observers, who fully confirm those obtained by Bernard. It is further stated by that experimenter, that ligature of the pancreatic duct arrests the emulsification and absorption of fat; but this, again, is disputed by others. The opposite conditions observed by them, are explained by Bernard, on the supposition, either that the smaller pancreatic duct escaped ligature, or that certain minute glands of the duodenum in part supplied the place of the pancreas. It has been asserted, that if the small intestine be tied, in cats and puppies, below the entrance of the pancreatic duct, and oil, mixed with milk, be injected into the bowel below the ligature, the lacteals, after a time, become filled with white chyle (Frerichs). It is also said, that after the formation of a pancreatic fistula in a cow, chyle collected from a fistula, subsequently made in the thoracic duct, contains almost as much fat as that of other cows in which no pancreatic fistula has been established (Colin and Lasaigne). Furthermore it is objected, that no large amount of saponified fat is found either in the contents of the intestine, or in the chyle itself, as might be expected, if the pancreatic juice decomposed the neutral fats, and so rendered them absorbable (Bidder and Schmidt).

To conclude: first, the pancreatic juice exercises a positive power of converting starch into sugar, and so may aid in digestion. Secondly, its digestive power over albuminoid and gelatinoid bodies, when it is fresh, is very slight, but more marked when it is acidified, or when it co-operates with the gastric juice. Thirdly, it possesses a remarkable power of emulsifying fat, and rendering it absorbable, more marked even than that of the bile. Lastly, whilst, out of the body, it not only emulsifies, but also decomposes the neutral fats into their fatty acids and glycerin. It is uncertain whether this decomposition actually takes place within the body.

A case has been recorded, in which a calf's pancreas, taken internally, aided the assimilation of fat; and, quite recently, preparations of pancreatin made from animals, like those of pepsin long employed, have been administered medicinally.

Action of the Intestinal Juices.

Owing to the mixture of secretions in the intestinal canal, it is difficult to determine the digestive properties of the intestinal juices. Portions of food, inclosed in perforated tubes, have been introduced through artificial openings, into the small intestine, the duodenum being first tied, in order to prevent the saliva, gastric juice, bile, and pancreatic juice, from passing down. Other experiments have been made, by isolating portions of the small intestine and its contents, by including them between two ligatures. Various kinds of food have also been subjected to artificial digestion, outside the body, at a proper temperature, in the juices of the small or large intestine, or with portions of the mucous membrane macerated in water. From such experiments, several conclusions are obvious. The strongly alkaline intestinal juice certainly converts starch into sugar, many believing that this change is chiefly accomplished in the small intestine; sugar itself here also passes into lactic and butyric acids; it acts still more powerfully in the solution of albuminoid substances. Lastly, it is also more or less capable of forming an emulsion with fat, and so of aiding the pancreatic juice, or even of supplying its place. It would seem, therefore, that the intestinal juice operates as an auxiliary digestive agent upon the three principal constituents of our food. Its effects do not appear to be interfered with by those of the other digestive fluids. The action of the secretion of Brunner's glands, and that of the intestinal juice, separately, are quite unknown.

Changes of the Food in the Small and Large Intestine. Contents of those Intestines.

In considering the changes in the food, which occur in any given part of the intestine, it must be remembered, that the fluids poured into the alimentary canal higher up, are still present, in greater or less quantity, in the intestinal contents lower down, and doubtless exercise some digestive influence. Thus, gastric juice, and even saliva, must be present in the upper part of the duodenum, and more or less pancreatic juice and bile in the lower part of the small intestine. The venous pulpy chyme, poured from the stomach into the small intestine, is acid, and brownish or variously colored; but on its admixture with the bile and pancreatic juice, it assumes a bright and yellowish color, and becomes much more opaque, owing to the addition of the biliary coloring substances, the decomposition of the acids by the bile, and the gradual emulsification of the fatty substances by the pancreatic juice. The contents of the upper part of the small intestine are still acid, partly from the acid of the gastric juice and partly from the acids of the bile, which are set free by the former; but their acidity is gradually diminished, not only by the alkaline pancreatic juice, but also, and chiefly, by the even more powerfully alkaline intestinal juice. The hydrochloric acid of the gastric juice is probably soon neutralized, and is then absorbed into the blood as chloride of sodium or common salt. At the lower end of the ileum, the reaction of the residual intestinal contents is generally stated to be alkaline; but near that point, in a case of accidental fistula in the human subject, it has been found acid, notwithstanding the alkaline condition of the mucous membrane. The contents of the cæcum are said to be acid; but those of the large intestine generally, to be alkaline. Much, however, depends on the nature of the food; for, from the formation of the acetic or lactic acid, during the use of an excess of vegetable diet, the contents of the whole intestinal canal may be acid. In carnivora, the contents of the cæcum, from the presence of ammonia, exhibit an alkaline reaction, whilst in the herbivora, they are always acid, from the presence of lactic acid.

The chemical composition of the contents of the small intestine is dependent on the nature of the food taken. It must also vary at different parts of the canal, according to the composition and quantity of the secretions mixed with it, and according to the relative quantity and nature of the substances which have been absorbed from it. Thus, the contents of the first part of the duodenum consist of the acid chyme, with bile and pancreatic juice, *i. e.*, of a mixture of the food taken, whether this be bread, milk, meat, or eggs, together with saliva, gastric juice, bile, pancreatic juice, and mucus, minus a certain amount of the water and dissolved substances, which have already been absorbed. These substances, which are almost exclusively absorbed by the bloodvessels, consist of saline matters, unaltered starch, sugar, whether pre-existing in the food, or produced by conversion of starch, dissolved albuminoid and gelatinoid substances, in the shape of albuminose and gelatin-peptone, salivin, pepsin, creatin and other extractive matters, and lastly, traces of alcoholic, ethereal, acid, and various sapid, substances. The sugar found *here*, is said, by some, to be grape sugar, the conversion of cane sugar into grape sugar being chiefly accomplished, in this part of the alimentary canal, by the agency of the intestinal juice. No fatty matter is yet absorbed, but it all remains in the contents of the upper part of the duodenum. Even after the admixture of the bile and pancreatic juice, all the substances just enumerated still continue to undergo solution and absorption, and the fatty matters, also now emulsified and rendered absorbable, are gradually taken up, together with some of the fatty acids of the bile. The contents of the small intestine are thus progressively robbed of all their dissolved or emulsified nutrient substances, in which they become by degrees poorer. Finally, passing into the large intestine, they acquire a greater consistence and a darker hue.

The contents of the large intestine have been supposed to undergo an imperfect secondary digestion in the cæcum; and there are reasons for believing that such a process, due to the action of lactic or other acids and of the intestinal juices, may, especially after heavy meals, be continued along the rest of the intestine. This may explain the digestion and absorption of the nutrient substances in enemas, by means of which the system, as is well known, may be for a long time supported. Whether starch is changed, or fat emulsified, is uncertain. The final residue consists chiefly of the insoluble or undigested portions of the food, broken down into small fragments. In it are found particles of vegetable matter, such as unaltered starch-grains, woody fibre, remains of vegetable epidermic and other cells, with portions of spiral and annular ducts. Of animal substances there are present portions of yellow elastic tissue, cartilage-cells, unchanged fat, epidermoid and epithelial cells, unchanged fragments of fibrous tissue, such as portions of tendon or fascia, and muscular fibres more or less altered, though having escaped complete digestion; besides this, there are certain earthy salts, especially the ammonio-magnesian phosphate, with the phosphates of magnesia and of lime. The neutral salts of the vegetable acids, such as the citrates, tartrates, malates, and benzoates of potash or soda, appear partially in the contents of the lower part of the large intestine, as carbonates, the rest having been absorbed, also, it is said, chiefly in the form of carbonates. Furthermore, the fecal mass contains coloring matters and other substances left from the almost completely changed or decomposed bile, such as cholalic and choloidinic acids, traces of cholesterin, and especially the substance named dyslysin, also a crystallizable substance containing sulphur, named *excretine* (Marcet), traces of stearic, margaric, and a peculiar fatty acid called *excreteric* (Marcet), with some animal matter, probably the residue of the pancreatic and the mucous secretions, especially of those of the larger intestine. It appears certain, indeed, that the glandular apparatus of the intestines serves to excrete, and thus eliminate from the blood, products of the decomposition of the tissues, which would be injurious if retained in it; these must be present in the fecal substance, and may in great part explain its odor. The small intestine, with its villous mucous membrane, is adapted to the function of absorption; but the non-villous mucous coat of the large intestine appears better adapted for excretory purposes. The percentage composition of the ashes of the daily quantity of feculent matter removed from the body, varies, according to the food, from 2 to 10 oz.; the average quantity is about 6 oz., of which three-fourths are water. The percentage composition of the ashes, after burning, is as follows:

Chloride of sodium, alkaline sulphates, and phosphate of soda (or potash),	4
Phosphate of lime and phosphate of magnesia,	81.5
Sulphate of lime,	4.5
Phosphate of iron,	2
Silica,	8
	100.

The contents of the stomach invariably include a certain quantity of atmospheric air (4 nitrogen to 1 oxygen), which has been mixed with the food and saliva in the mouth, and swallowed with them. The decomposition of the amylaceous and saccharine food into lactic and butyric acid, may cause the evolution of carbonic acid and hydrogen. The oxygen, and especially the carbonic acid, being more soluble in water, would be more easily absorbed than the nitrogen and hydrogen; but the nitrogen may also pass into the blood. An interchange of the other gases with carbonic acid from the blood may take place, by what might be termed *intestinal respiration*. In the small intestine, the carbonic acid and hydrogen relatively increase in quantity, the nitrogen remaining about the same; whilst the oxygen disappears. On including a loop of the small intestine of a living animal between ligatures at two different points, the gases of the blood, oxygen, carbonic acid, and nitrogen, have been found to pass into the interior of the intestine; so that these gases may be both absorbed from, and excreted into, the intestinal canal. In the large intestine, besides carbonic acid, as the principal gas, carburetted hydrogen may appear, owing to the slow decomposition of its contents; nitrogen abounds after a flesh diet, and hydrogen after a milk diet; lastly, though, it would seem, but seldom, as a consequence of the decomposition of the albuminoid substances containing sulphur, or of the taurin of the bile so rich in that element, or possibly from the deoxidation of sulphates, small quantities of sulphuretted hydrogen gas are evolved. These two last-mentioned gases may also be absorbed into the blood; indeed, it has been shown experimentally, that animals may be quickly poisoned by injecting sulphuretted hydrogen into the large intestine.

The time taken by different articles of diet to descend through the alimentary canal, varies. Laxative medicines may pass in four hours, carbonate of iron in twelve hours, the coloring matter of spinach and other vegetables in eighteen hours, and grape-pips and cherry-stones in from three to four days. It has been shown that it is useless, and perhaps imprudent, to administer purgatives *immediately after* the accidental swallowing of buttons, coins, or stones; it is better to administer thick tenacious food for a day or two, and then give a dose of castor oil.

Summary of the Chemistry of Digestion.

We have seen that the digestible and absorbable parts of food consist chiefly of the carbhydrates, or the amylaceous, gummy, and saccharine substances; of hydrocarbons, or fats and oils; of nitrogenous gelatinoid and albuminoid substances, and extractive matters; of hydrocarbonaceous alcohol and organic acids; of saline substances, and of water.

Part of the *starch* is converted, by the saliva in the mouth, into glucose or *grape sugar;* this change still goes on in the stomach, even in the presence of the gastric juice; it is completed, or, according to some, chiefly accomplished, in the interior of the small intestine, by the continued action of the saliva, and by the superadded agency of the pancreatic and intestinal juices. Cooked starch is changed more rapidly than raw starch, the cells of which sometimes escape digestion; the emptied envelopes of the starch grains commonly remain undigested. Cane sugar (Bouchardat), and milk sugar (Lehmann), are for the most part converted into grape sugar in the stomach, more particularly in the intestine; small quantities of cane sugar are said to be absorbed without change (Bernard). The grape sugar, thus formed from starch and other sugars, or that which may be contained in the food, is principally absorbed as such by the bloodvessels; but it appears partially to be changed, especially when abundantly taken, within the alimentary canal, into lactic acid, and this again into butyric acid, with an accompanying separation of carbonic acid and hydrogen. Thus:

$$\text{1 Grape sugar} = \text{2 Lactic acid} = \begin{cases} \text{1 Butyric acid} \\ \text{2 Carbonic acid} \\ \text{4 Hydrogen} \end{cases}$$

$$C_6H_{12}O_6 = 2\,C_3H_6O_3 = \begin{cases} C_4H_8O_2 \\ 2\,CO_2 \\ 4\,H \end{cases}$$

The *albuminoid* bodies begin to be digested in the stomach, by the gastric juice; whilst their solution is continued, and completed, in the small intestine, by the additional action of the intestinal juice. Fluid albumen, and especially vegetable albumen, and coagulated fibrin, are easily digested; coagulated albumen, casein, gluten, and legumin, more slowly. Casein is first precipitated in a flocculent form, and then dissolved. All albuminoid substances are converted at once into albuminose or albumen-peptone. Gelatin and gelatin-yielding tissues are converted into gelatin-peptone. These peptones, and also the saliva, pepsin, and pancreatin, are absorbed from the stomach, as well as from the small intestine, and chiefly by the bloodvessels.

Fats, whether pure, and merely melted by the heat of the stomach, or whether forming part of an organized tissue, and set free by the digestion of the enveloping areolar tissue and walls of the adipose cells, coalesce into small drops in the stomach and upper part of the duodenum. In the small intestine, so long as its contents remain acid, the fats are merely emulsified by the pancreatic juice, aided possibly by the bile; in the lower portion of the small intestine, however, where the intestinal contents become more or less alkaline, certain quantities of the fat are probably decomposed into their fatty acids and glycerin, by the further action of the pancreatic juice, and may even be saponified by the strongly alkaline intestinal juice. Thus emulsified, decomposed, or saponified, all but a small residue of the fatty matters are absorbed by the lacteals of the intestines.

Alcohol, in all its forms, *ethers* and other soluble *acid* and *sapid* bodies, are absorbed unchanged, along the whole surface of the alimentary canal, chiefly, if not entirely, by the bloodvessels. This absorption begins even in the mouth, otherwise these substances would produce no flavor. The organic acids probably decomposed into carbonates.

The *extractive* matters, creatin and creatinin, the cerebric acid, those which are uncrystallizable, and perhaps some of the cruorin and myochrome, are also probably absorbed without change, by the bloodvessels.

The *saline* constituents of the food are chiefly absorbed without alteration; the soluble ones, from the mouth, stomach, and intestinal canal generally; whilst the less soluble phosphates of magnesia and lime, appear rather to be dissolved in the large intestine. Any carbonates contained in the food or drink, must be decomposed by the acids of the gastric juice, by the lactic acid of the food, and by the acids resulting from the decomposition of saccharine matters. The salts formed by such organic acids with soda or potash, are either absorbed into the blood, and there converted into carbonates, or they are thus changed in the intestinal canal.

Water remains undecomposed, and is absorbed freely during the digestive process, constituting the natural menstruum, in which the different soluble substances are dissolved, and in which the fatty matters are suspended.

Of substances the digestion of which is doubtful, may be mentioned vegetable mucus, gums, pectin, and cellulose. The three former, though soft and tender substances, miscible but probably not actually soluble in water, are said by some, indeed, neither to be capable of being absorbed, nor yet to be so chemically changed as to become so. The softer kinds of cellulose, such as that contained in the growing tissues of green vegetables, in the tuber of the potato, and in the pulp of fruits, are supposed to be dissolved in small quantity, if not for nutrient purposes, yet in order to set free their starchy, gummy, saccharine, and albuminoid contents. Herbivorous animals, however, certainly digest large quantities of cellulose and vegetable pectin, by changing them into sugar. Chlorophyll, speaking generally, is indigestible. Though putrescent meat, such as high game, may be first sweetened, and then digested by the gastric juice, yet certain decomposing substances, like poisonous or fermenting sausages, cannot be corrected by the juices of the stomach, but excite vomiting and diarrhœa, and, when absorbed, often prove fatal.

Circumstances which Modify Digestion.

The rate of gastric digestion of certain articles of diet has already been mentioned (p. 552). It partly depends on the relative solubility of the various proximate constituents of the food; but it may also be greatly modified by other circumstances, such as the quantity, consistence, and peculiar mixtures of the food, its condition of subdivision, its absolute quantity, the relative quantity of its different constituents, the absence or presence of stimulating substances, the conditions of the nervous system, the state of sleeping or waking, the condition of the body as regards health, habit, individual peculiarities, bodily fatigue, and even the condition of the mind. Rest and exercise also affect the digestive process.

The more rapidly and perfectly the constituents of any given kind of food are capable of being dissolved, the more easily such food is digested, and *vice versâ*. As a rule, bread, not too new, nearly all kinds of meat, poultry, and white fish, eggs, milk, jelly, and the gelatin-forming tissues, and well-boiled potatoes, are easy of digestion; whilst new bread and potatoes, fatty meats, fat, tendons, cartilage, cheese, and green vegetables, are more difficult of digestion. Hard-boiled eggs are, of course, more difficult to digest than the fine coagulum of albumen formed in a custard, or in the gravy of meat, owing obviously to the difference of consistence and degree of subdivision in the two cases. Mashed potatoes and finely grated cheese, and soft cream- and milk-cheeses, are more easily and rapidly digested than plain boiled potatoes or hard cheese. Again, all vegetable substances too much matured, and therefore composed of cells having harder cell-walls, are more difficult to digest, and hence require much cooking, and artificial subdivision, to burst and break down the cells, and permit the digestive juices to enter their interior, and act on their contents. Carrots, turnips, cabbages, celery, artichokes, asparagus, and onions, may be classed in this category. Even the cooking of flour, and of all other amylaceous articles of diet, helps digestion in an extraordinary degree, by bursting or swelling the fecula or starch grains. Large quantities of adipose tissue, intermixed with muscular tissue, probably impede the penetration of the gastric juice, and so render too fat meats, such as pork, and also oily fish, as, for example, salmon, comparatively indigestible. It has been found that the flesh of animals living in a wild state, is more digestible than that of the allied tame species, probably owing to the more fatty muscular tissues of the latter. A large quantity of fat, in the shape of fatty tissue, taken with other food, may have the same effect of interfering with digestion; but such fatty tissue is far preferable to fat itself, and more easy of digestion, because it is contained in areolar tissue, and is divided into minute spherules within the fine adipose cells, so that the gastric juice percolates it with comparative facility. Hence suet and cooked fat are more digestible than the melted fat derived from them, and swimming on the surface of gravy. Pure solid fats having a granulated texture, especially cold butter, the particles of which adhere together, as it were, only by certain points of contact, are more easily digested than the same fats taken in a melted condition, such as oiled butter, in which the oleaginous particles have completely coalesced. It is possible, also, that the heating of fatty matters determines slight chemical changes, inconsistent with easy digestion. But perhaps the most objectionable effect of fat, is that which occurs in certain processes of cooking, in which it saturates heated or dried albuminoid, gelatinoid, or amylaceous substances, and so preoccupies their interstices, as to render them extremely difficult of penetration by the gastric juice, which is aqueous, as in the case of buttered toast, or greasy hot dishes of any kind. Moreover, owing to the high temperature in roasting or baking, the substances above mentioned, as well as the fats themselves, sometimes undergo peculiar chemical changes, by which acrolein, or other pyrogenic compounds are perhaps developed. These latter conditions are met with in the burnt parts of roasted joints, in over-roasted, baked, or fried parts of the skin of poultry or of fish, and especially in greasy and burnt pie-crust.

It would seem that animal albuminoid substances, held in solution, as in soups and broths, are not more easily digested than the same substances in a solid form; for the water requires to be almost entirely absorbed, before the nutrient principles can be converted into peptones. Hence, solid food, even in the case of many invalids, is more suitable than bulky fluid food. It is said that dextrin, introduced into the system, favors the digestion of albumen (Schiff); this affords an illustration of the advantage of mixed diets.

Too large a quantity of food, at any one meal, also renders digestion proportionally difficult. When the digestive powers are weak, the bad effect of quantity is much more obvious. It is believed that the secretion of the gastric juice especially, is regulated, as to quantity, more by the demands of the body, than by the amount of food taken; hence, an excess of food not only remains undigested, but acts as an irritant to the stomach itself, lessening its further secreting power, and, if passed on into the duodenum, causing more or less disturbance to the system. At the same time, some solid substance is essential or favorable to digestion; hence, perhaps, the habit of certain nations, mixing, with their scanty food, some indigestible material, such as sawdust or earth, which can only increase its bulk. After a very heavy meal has been digested, the stomach secretes but a very weak gastric juice (Schiff).

The effects of cold water, or ice, in repressing the secretion of the gastric juice, and so retarding the digestive process, have been already mentioned; the reduction of the temperature of the stomach, and the retardation of the capillary circulation, afford an explanation of these facts; taken in large quantities, with or after food, ices and iced beverages must suspend digestion. On the other hand, digestion is undoubtedly favored by moderate quantities of alcohol, also by salt, vinegar, lemon-juice, pickles, sauces, and spices, these substances acting as stimulants to the secreting processes necessary for digestion, especially to that of the gastric juice; vinegar, moreover, contributes, by its acidity, to swell and pulpify albuminoid substances. Lemon-juice yields, in addition, potash salts to the blood. Wines and beers also contain potash, magnesia, and lime; the red wines, especially, yield small quantities of tannin, and traces of iron.

Severe exercise of the body, or active employment of the mind, too soon after a meal, hinders digestion; even moderate exertion of the body is not desirable immediately after a full meal, rest being found decidedly to favor digestion; but persons of sedentary habits digest slowly. Sleep is said to retard this process, but otherwise does not interfere with it. Mental emotion may arrest digestion, perhaps, by putting a stop to the secretion of gastric juice. Digestion, as already mentioned, requires for its due performance, the secretion of large quantities of the digestive fluids, and this can only be accomplished by an increased supply of blood to the organs concerned in this function; hence, any acts which determine the blood strongly to the brain or muscles, interfere with it.

Habit has an extraordinary effect in modifying the digestive power in particular instances; thus, infants or invalids, who have been habitually fed on fluid and easily digested food, are inconvenienced, or injured, by the use of hard food difficult of digestion, and can only by degrees acquire, or regain, a stronger digestive power. Those persons, even, who are accustomed to take food of a dry and hard nature, and requiring strong digestive powers, have their digestive organs deranged by the use of soft and succulent food, which they can only properly digest after a kind of education. A certain effort in the digestive act is probably beneficial, as it is natural to the system.

Custom, and differences of climate, explain the well-known national peculiarities of diet, and also the fact that, as a rule, a foreign dietary, unless modified, or gradually adopted, is less adapted to the digestive powers of individuals of different nations and climates.

Finally, the effects of individual differences, or, as they are called, *idiosyncrasies*, are truly remarkable in the case of the digestive functions. In certain instances, particular, and perhaps not otherwise difficultly digestible, substances invariably produce the most serious pain and disorder; whilst substances ordinarily indigestible, may perhaps be readily digested. Thus, for example, oysters, lobsters, crabs, and salmon, will each produce, in different persons, severe attacks of indigestion, and even give rise to eruptions on the skin. In some persons, strawberries are known to produce a similar effect; and to others, cucumber is almost a certain poison.

Relative Value of Different Foods.

The following Table, chiefly from Vierordt, exhibits the composition of a few of the great variety of articles of food consumed by Man. It shows the total amount of solids, and the proportions of organic proximate constituents, salts, and water, in each article of diet; also the relative amount of its nitrogenous and non-nitrogenous constituents, and, as regards the latter, the respective quantities of oleaginous, amylaceous, and saccharine matters. The relative value of different articles of diet, for plastic or tissue-forming purposes, for calorific or respiratory purposes, or for maintaining the proper saline constitution of the blood, is thus shown, so far as their chemical composition is concerned; but this alone affords no sufficient indication for the practical choice of diet in individual cases, so much depending on the physical characters and mode of preparation of food, as well as on the age and idiosyncrasies of the individual.

The total quantity of solids, shown in the first column of the following Table, reveals the highly nutritive quality of leguminous and cereal food, butter, cheese, and eggs, in comparison with meat; but such general comparisons are inexact, for the proportions of non-nitrogenous and nitrogenous substances, in each kind of food, are not taken into account. As regards the latter, cheese is the most nutritious diet, then the leguminous seeds, next meat, and then, in order, the yolk of egg, flour, the white of egg, and bread. As regards fat, the order of nutritive value is, butter, yolk of egg, and cheese. Starch and sugar are most abundant in wheat, next in the leguminosa and the inferior cereals, less so in potatoes, and least in the succulent vegetables and fruits.

Cheese is an extraordinarily concentrated diet; the leguminosa are highly nutritious, especially those grown in hot countries, but they require a thorough preparation and good cooking; the great merit of bread is its soft, porous, permeable, and well-cooked substance; the advantage of meat consists in its concentrated, yet succulent, tender, and easily digested substance, and in its containing the very elements of the tissues and the blood, even fat, creatin, and the potash salts. Potatoes are a weak food, one pound being only equal to about six

Food.	Total Solids.	Albuminoids.	Gelatinoids.	Fatty.	Starchy, Saccharine, Gummy.	Cellulose, Lignin.	Extractives, Creatin, &c.	Salts.	Water.	Remarks.
Meat, ...	26	Sy. 16, Al. 2	2	3			2	1	74	Also Myochrome and Cruorin, and often Glycogen.
Broth (common),	1.5	Small quan.	.5	Small.			.3	.3	98.5	Strong broth, 3 per cent. of solids.
Brain, ...	24	Al. 8		15			?	1	76	
Liver, ...	29	Al. 13.5	5	3.5	St. or Su. 1–2		4.	1	71	The Starch is Glycogen.
Egg (yolk), . .	48	Vit. 17		29			1	1	52	
Egg (white), . .	15.5	Al. 11		1–2	Su. traces.		2	.5	84.5	Cerebric Acid. The white is twice the weight of [the yolk.
Milk, ...	13	Cas. 4–5		4.	La. 4.			.5	87	
Cheese, . . .	62	Cas. 33		24				5.	38	Some volatile fatty acids.
Butter, . . .	78.5	Cas. 1.5		77					21.5	
Wheat Flour, .	98—87	Gl. & Al. 13		1	St. 61.	3.5		1	12–13	Indian corn especially contains Cerebric Acid.
Wheat Bread, .	57	Gl. & Al. 9			St. 34, Dex. 11, Su. 2			1	43	
Rye Bread, . .	55.5	Gl. & Al. 9			St. Su. and Dex. 40	5.		1.5	44.5	
Peas, ...	86	Le. & Al. 23		2.	St. Dex. and Su. 53	4.	2	2	14	
Lentils, . . .	89	Le. & Al. 27		2.5	St. Dex. and Su. 56	2.	?	1.5	11	Some of the Sugar is Inosite.
Potatoes, . . .	26	Al. 1–2		1.5	St. 13, Dex. 2	6.	1.5	1.	74	
Carrots, . . .	15	Al. 1 5		.3	Su. and Dex. 8	3.		1.5	85	
Cabbages, . .	21	Al. 2.		.3	Su. and Dex. 14	3.		2.	79	
Apples, . . .	18	Al. .5			Su. and Dex. 8	8.		.5	82	Organic Acid 1.
Cherries, . . .	25	Al. .7			Su. 8–11	1.3		.7	75	Organic Acid .5–1.
Grapes, . . .	19	Al. .7			Su. 15	1.5		.5	81	Organic Acid .7
Wine, ...	14—8				Su. .5		.3	.2	86–92	Organic Acid .5. Phosphates. Alcohol 5–12, Æther, traces. In Red Wine, Tannic Acid.
Beer, ...	10—7	Traces.			Su. and Dex. 6			.2	90–93	Alcohol 2–5. Oil of Hops.

Abbreviations.—Al. Albumen; Sy. Syntonin; Cas. Casein; Vit. Vitellin; Gl. Gluten; Le. Legumin; St. Starch; Su. Sugar; Dex. Dextrin; La. Lactin.

ounces of bread, and four ounces and a half of lentils; they are not much more nutritious than the succulent vegetables, but, like these and fruits, they contain, which bread does not, potash, so essential to the muscles; hence, perhaps, their utility in preventing and curing scurvy.

A well-selected vegetarian diet is quite equal to the maintenance of life and health; the Japanese, the Hindoos, and the lazzaroni of Naples, subsist chiefly on a vegetable diet. The macaronis and vermicellis are composed of gluten, with but a small proportion of starch. Indian corn, and also wheat, though not in such quantity, contain cerebric acid, a remarkable nitrogenous compound, found in the nervous substance, of very high atomic constitution. Broth is a very weak nutriment, even when some strong farinaceous element is added to it; so is beef-tea, if properly prepared. Meat contains principles which may be extracted, some better by cold water, others by warm water, and others, again, by boiling; it should, therefore, be cut into small pieces, be submitted for three hours each time, in succession, to half its weight of *cold*, of *warm*, and of *boiling* water; the fluids, strained off from the first and second macerations, are to be mixed with that strained off hot from the third or boiling process, and the mixture should be just brought to a boiling heat to cook it; the fat should be skimmed off; a few drops of some acid, with salt, will increase the flavor. Thus prepared, beef-tea contains albumen, traces of syntonin, fibrin, cruorin, and myochrome, in a flocculent state; and gelatin, creatin, cerebric acid, perhaps glycogen, inosite, paralactic, lactic, and inosinic acids, and salts of potash, soda, and magnesia, in a state of solution; nearly all the syntonin remains in the shrunken meat; the fat is never absolutely removed. Beef-tea, if good, is a light, nutritious, easily assimilated, conservative, and stimulating food. The now much used *extractum carnis* or *extract of meat*, is the inspissated juice of meat, and resembles a viscid beef-tea; but it contains no gelatin, and no glycogen or sugar; to be truly nourishing, it requires the addition of some albuminoid and amylaceous materials. Malt liquors are more nutritious than weak beef-tea. Alcohol stimulates and develops heat; it seems to be partly digested and oxidized, though a great portion escapes unchanged by the lungs, skin, and kidneys.

THE ORGANS AND FUNCTION OF DIGESTION IN ANIMALS.

The process of digestion, by which food is dissolved and rendered absorbable by the living body, is almost universally performed by animals; and a digestive apparatus is found in nearly all animals, a few Entozoa and most Protozoa excepted.

The general idea of such an apparatus, is an internal digestive cavity, communicating with the exterior. The plan of construction of this internal receptacle, presents a general resemblance in each separate Subkingdom, but in each, it offers further modifications. These are the most varied and detailed in the Vertebrata, but they exist also in the Mollusca and Annulosa, and may be traced in the Molluscoida, Annuloida, and even in the Cœlenterata. In the Vertebrata, the plan is not only modified in each Class, but, in the Mammalia especially, it presents peculiar adaptations, suiting it to the carnivorous, insectivorous, frugivorous, herbivorous, omnivorous, and marine habits of the animals composing its several Orders. The digestive apparatus becomes, indeed, like the rest of the economy, more complex as we ascend in the animal scale; and its diversities of form and structure become most obvious in the highest groups.

The digestive cavity usually takes the form of an *alimentary canal*, which, in its perfect condition, presents two orifices, an inlet, and an outlet. It is usually divisible into an œsophagus or gullet, a stomach, and an intestine. Its relative length and capacity, and the complication of its superadded parts in any given case, have reference chiefly to the nature of the food. Thus the vegetable-feeding species of any group, be it Order, Class, or Subkingdom, have a longer, more capacious, and more complicated apparatus, than their congeners which live upon animal food. This fact is illustrated by comparing the snail with the oyster, most insects with spiders, the caterpillar with the perfect insect, the tadpole with the perfect frog, the vegetable-feeding turtles and tortoises with the carnivorous fishes, the granivorous with the carnivorous birds, and the herbivorous with the carnivorous quadrupeds.

It is said that the intestine of the domestic cat is longer than that of the wild cat, and even that the same is the case with the vegetarian races of men, as compared with men generally. The greater length and complication of the alimentary canal in vegetable feeders, are owing to their food requiring more prolonged digestion than an animal diet; its increased capacity is due to the fact, that to obtain a given quantity of nutriment capable of supporting life, a greater bulk of vegetable food is required than of animal food, particularly so when that consists, not of fruit and seeds, but of grasses, or the green parts of herbs and trees, as is the case with the food of the Ruminants, Solipeds, and Pachyderms.

The digestive apparatus is also modified to suit the physical condition of hardness or softness of the food, and the various modes in which the animal must seize, crop, and masticate it; hence the existence of modifications in the prehensile and masticatory apparatus, the mouth, teeth, and gizzard. Furthermore, the periods of feeding influence the form of the digestive organs; animals of the same order, Ruminants for example, which feed constantly, having a simpler construction of the stomach than those which, by instinct or necessity, take food or drink at longer intervals; hence the great capacity of the stomach and large intestine in the Ruminants, Solipeds, and Pachyderms generally, the existence of water-cells in the paunch of the camel, and the presence of large crops in many granivorous birds. In the Class of Birds generally, an example is met with of a modification dependent on the plan of the Class itself; for a heavy external masticating apparatus, connected with the head, being inconsistent with the organic aim of construction for flight, an internal crushing apparatus, or gizzard, is present where the food requires it.

Prehension of Food in Animals.

Mammalia.—The prehensile limbs of the Quadrumana seize the food, and transfer it to the mouth. In the feline tribe, the paws serve to capture living prey, but do not convey it to the mouth, this being accomplished by movements of the head and jaws. In many Rodents, as in the squirrel, rat, mouse, and guinea-pig, and also in the kangaroo, and other Marsupials, the two anterior limbs are often used together for holding food, and approximating it to the mouth. In most Mammalia, however, the anterior limbs are organized for locomotion, and the jaws and teeth are the instruments used for capturing or cropping the food, and for its introduction into the mouth. In all cases, the lips are employed. The act of sucking, characteristic of all young Mammalia, and that of drinking in the adult, is performed by the lips, cheeks and tongue, and the lapping of the Carnivora, by the latter organ only.

Special contrivances for the seizure of the food, are noticed in the snout of the tapir, the proboscis of the elephant, the long tongue of the giraffe, and the extensible viscid tongue of the ant-eaters. The marine and piscine Cetacea, have either rudimentary or no limbs; some, like the dolphin and porpoise, seize their prey by means of their many-toothed jaws; the whalebone whale opens its huge mouth, as it moves through the water, which, entering that cavity, filters through the numerous whalebone plates, descending from the upper jaw and fringing the sides of the mouth, and so leaves multitudes of soft marine creatures, Pteropods and others, in the interior of the mouth, ready to be swallowed; lastly, the vegetable-feeding dugong employs its lips and jaws. The ornithorhynchus takes its food by its duck-bill horny mandibles. In a few Mammalia, as in certain Quadrumana, Bats, and Rodents, cheek-pouches exist for the temporary reception of food; these are very large in the hamster and opossum.

Birds.—The raptorial species, and also the parrots, use the foot prehensively, as well as the jaws. In most birds, however, the bill is the substitute for the tooth-bearing jaws and fleshy lips of the Mammalia, and the shape of this most characteristic part in Birds, is variously modified to suit the character of the food. Thus, it is short and strong in the granivorous sparrows and linnets; long and tender in the small insectivorous warblers and fly-catchers; notched in other insectivorous birds, as in the shrikes; short and gaping in the swallows and night-jars, which catch their prey upon the wing; strong and hooked in the rapacious eagles and vultures, which tear up their food; long, conical, and of great strength, in the digging rook, and in the woodpeckers, which pierce the bark of trees; short, curved, and of great depth in the parrot tribe, which can crush hard nuts; exceedingly delicate and tapering in the humming-birds, to enable them to penetrate the tubular corollas of flowers; ponderous and ungainly in shape, in the toucan and the adjutant; long, strong, and pointed, for the catching of fish, in the herons, storks, and kingfishers; elongated and suctorial, in the snipes and sandpipers, which seek their food in bogs or sands; flattened, grooved, and sensitive, in the ducks, geese, swans, and spoonbills; or it presents still other forms, for holding fish, as in the pelicans, pilgrims, albatross, penguins, and auks. In the cross-bills, the mandibles, when closed, pass by each other so as to present the appearance of a deformity, but this peculiar conformation enables them to extract, with great facility, the seeds from the fir cones. The young pigeon is fed on the regurgitated contents of the crop of the mother-bird. This is accomplished, not, as is usually stated, by the mother placing its bill in the mouth of the young bird, but by the very opposite manœuvre. The lower mandible of the young pigeon is elongated and boat-shaped, and, for a time, of disproportionate size as compared with the upper mandible; hence it forms a sort of spoon for the reception of the food taken from the gullet of its parent; as the pigeon grows, the lower mandible becomes relatively smaller (Tegetmeier). In the parrots and woodpeckers, the tongue is prehensile.

Reptiles.—These, like birds, have no lips. They capture their prey with the jaws, which are horny in the Chelonians, have small teeth in the Ophidians, powerful teeth in the larger Saurians, and delicate and even complex teeth in the small insectivorous species. The limbless serpents crush their prey in their coils, before swallowing it. The prehensile tongue of the chameleon is well known.

Amphibia.—In these animals, the soft lips and jaws are sometimes provided with minute prehensile teeth; the food is taken by a snapping movement. The tongue of the toad has been already referred to (p. 198).

Fishes.—By these, the food is invariably seized by the jaws, which are usually provided with numerous sharp recurved teeth; though, in some species, the mouth is suctorial, and the teeth are few, or even wanting. In the amphioxus, the oral orifice is guarded with soft *cirrhi*, whilst the mucous membrane of the mouth is provided with ciliated processes; the food is perhaps conveyed into the mouth by ciliary action.

Mollusca and *Molluscoida.*—The so-called feet of the Cephalopods serve to convey food to the mouth; but the tentacula generally present in Molluscs, are sensory rather than prehensile, the food being seized by the mouth, as in the terrestrial and in certain aquatic Gasteropods, or brought thither by currents of water caused by movements of the mantle, or by cilia, as in the Lamellibranchiata. In the molluscoid Polyzoa, the ciliated tentacles around the oral aperture produce a vortex, by which minute organisms in the water are hurried into the pharynx. In the Tunicata, the cilia lining the fore-part of the alimentary canal, accomplish a similar purpose.

Annulosa and *Annuloida.*—Most Annulosa have distinct buccal appendages, consisting of two pairs of jaws; the first pair are the *mandibles* or *pincers;* the second are the *maxillæ*, which support the *palpi*. By these parts, the food is seized, examined, or even divided. In many Insects and Crustacea, and in Spiders, one or more pairs of the limbs are also employed in conveying food to the mouth; sometimes, as in the crabs and lobsters, such limbs are enormously developed, the pincers on one side of the body being smooth, and on the other, knobbed. In certain perfect insects, the food being viscid or fluid, the mandibular appendages are specially modified, as *e. g.*, in the butterflies and moths, in which they form a long tube or canal named the *proboscis*, which can be unfolded from its spiral coils and protruded into flowers; a sucking proboscis also exists in certain flies and gnats. In the fleas and bugs, the mandibles are penetrating and suctorial. Amongst the Annelides, the sand-worms have soft feeble tentacles; but the earth-worms and leeches have the mouth either simply suctorial, or cutting and suctorial. In some worms, a retractile proboscis exists, developed from the lining membrane of the pharynx, and not from the cephalic segments of the exo-skeleton, like the jaws of the higher Annulosa. The Annuloid Entozoa either have a special suctorial apparatus, or live by general imbibition. The marine worm-like forms are suctorial, whilst the Rotifera have a ciliated disc, which creates a vortex in the water. In the starfishes and echini, there are no prehensile tentacula; in the Crinoida, the arms may act prehensively; in the holothurida or sea-cucumbers, large labial appendages or tentacula exist.

Cœlenterata.—These exclusively aquatic animals have contractile non-ciliated tentacles, sometimes few and simple, or divided, as in the hydra, sometimes very numerous, as in the sea-anemones, and often of great length and of irregular form, as in the medusæ and others. These are always prehensile; but food may also be drawn into the body, by the alternate expansion and contraction of its muscular walls. In the Physograda, the mouth is developed into depending tubular suctorial processes or cirrhi.

Protozoa.—In the Infusoria, the cilia draw the water and food into the buccal orifice, and there is no other prehensile apparatus. In the lowly-organized Rhizopods and Amœbæ, the soft body is merely applied to the substance serving as food. In the Spongida, currents of water are drawn through numerous incurrent or inhalant orifices, into the interior of the porous mass, whilst excurrent or exhalant orifices, fewer in number, serve for their expulsion. This process not only assists in respiration, but also in entangling food against their sarcodous substance. Finally, the parasitic Gregarinida live by direct imbibition.

The Teeth and Mastication in Animals.

True teeth, or calcified organs, belonging to the exo-skeleton, and composed of *dentine*, or of this with *enamel* and *cement*, are peculiar to the Vertebrata; for the so-called teeth or *denticles* of certain Mollusca, Annulosa, and Annuloida, have no such structure.

Teeth are entirely absent in Birds; but they are generally, though not universally, present, in Fishes, Amphibia, Reptiles, and Mammalia. In the last-named Class alone, are the characteristic *milk* teeth met with, that first temporary and deciduous set, which falls out and is succeeded by the permanent teeth. With the exception of a few fishes, and the vegetable-feeding iguanas amongst reptiles, which have grinding teeth, these organs in Fishes, Amphibia, and Reptiles, are essentially prehensile, or incisive, being used for seizing, and holding the prey, or for dividing it into portions small enough to be swallowed; but it is in the Mammalia, that *mastication* proper, performed by teeth set in movable jaws, is most perfect, the food being, in many of them, not only seized, but afterwards gnawed or chewed.

In the different classes of the Vertebrata, the teeth differ remarkably in number, shape, position, and mode of insertion.

Mammalia.—Amongst these, the Monotremata are almost edentulous, or destitute of teeth, for the echidna has no such organs, but merely horny processes on the tongue and palate, whilst the ornithorhynchus has horny teeth. In the Cetacea, two genera have calcified teeth *before birth* only, the upper jaw afterwards supporting the whalebone plates. In the manis, or pangolin, and in the true ant-eaters, or myrmecophaga, amongst the so-called Edentata, there are likewise no teeth. All other Mammalia possess them.

The *number* of the teeth in the Mammalia, in conjunction with other differences in shape or kind, furnishes an important means of zoological distinction. It ranges from 2 in the narwhal, to as many as 190 in the dolphins. In the elephant, there are at most 10, usually only 6, viz., one entire molar, or sometimes parts of two, on each side of both jaws, together with the two tusks of the upper jaw. In the Rodents, the ordinary number is 20, but there are sometimes only 12, and in the hare and rabbit 28. In the Ruminants, in the apes of the Old World, and commonly throughout the Mammalia, as in Man, there are 32, but 44 is said to be the typical number. (Owen.) In one of the armadilloes, as an exception to the rule in that genus, there are 98 teeth. Amongst the Cetacea, the narwhal, just mentioned, and some other species, have only 2 teeth; the cachalot has more than 60, the common porpoise between 80 and 90, and the true dolphins from 100 to 190.

The *form* of the teeth presents greater variety in the Mammalia than in any other Class. When numerous, they are usually prehensile, small, pointed, and of nearly equal size throughout the jaw; sometimes slightly recurved, and sometimes variously flattened or compressed. When the teeth are in moderate number, some are devoted to one purpose and some to another, and they are usually modified into incisor, canine, premolar, and molar teeth. The incisors, as in Man, are flat, chisel-shaped, and cutting or gnawing; the canines are larger and conical, to bite, hold, and tear; the premolars and molars are variously cusped or tuberculated, and either flattened at the sides for cutting, or broad at the summit for grinding the food. The incisor teeth are smallest in the insectivorous, larger in the carnivorous and frugivorous species, of great strength in the cropping Herbivora, but especially strong in the gnawing Rodentia. The canine teeth, prominent in the carnivorous dogs and cats, are also large in many non-carnivorous animals, as the ape, boar, musk-deer, elephant, and others, in which they are used for offence or defence. The carnivorous molars are generally flat, narrow, ridged, and tuberculated, the anterior ones being often very diminutive. The herbivorous molars are flat-crowned, quadrangular, or lozenge-shaped, and provided with tubercles, as in the Quadrumana, or marked with crescentic or transverse ridges and furrows, as in the Ruminants, Solipeds, Pachydermata, and Rodents. In animals living on mixed diet, the crowns of the molar teeth are furnished with blunt tubercles. The tusks of the elephant are huge canine teeth; those of the walrus are also canine. The single tusk of the male narwhal or Monodon, several feet in length, is also an upper canine tooth; it springs on one side of the median line, from the superior maxillary bone; but an immature tooth is found concealed in the bone of the opposite side; in the female narwhal, both tusks remain undeveloped, one in each upper jaw-bone. The curved canine tusks of the Babyroussa are also remarkable; those of the upper jaw are larger and longer than those of the lower jaw, and sometimes perforate the upper lips.

The teeth in Mammalia are limited to the jaws. They are confined to the inferior maxilla in the cachalot, to the premaxillary bones in the upper jaw in the narwhal, and to the superior and inferior maxillary bones, being wanting in the premaxillary bones, in most Ruminants. But usually, teeth are found in all three of these bones. However varied in number and in form, mammalian teeth are always arranged, in each jaw, in a single row or dental arch, in which, where different kinds of teeth exist, one or more gaps occur, named *diastemata*. When a diastemata is absent, the teeth are of equal length. In the human jaw, as already mentioned, there is no diastema, but this is also the case in certain extinct quadrupeds.

The mammalian teeth are usually fitted closely into sockets in the jaws, each tooth and each fang, if these be multiple, having its own socket, lined by a periosteum which fixes it. In certain Cetacea, the sockets are wide and shallow, and the teeth are attached to the gum, rather than fixed in the jaw. Each tooth generally has a constricted part or neck, between the crown and fang, to which the gum is fixed; but no neck is seen in the numerous small teeth of the dolphin, in the tusks of the narwhal, elephant, and walrus, or in the incisors of the Rodentia.

The teeth of most Mammalia, like those of Man, consist chiefly of dentine, the crown being protected by enamel, and the fang being covered by the cement, which sometimes passes over the crown also. The microscopic structure of these tissues, however, presents certain minute peculiarities. The tusks of the narwhal, walrus, and elephant, are destitute of enamel, and consist almost wholly of the modification of dentine known as *ivory*, the surface being at first covered by a thin layer of cement, which becomes worn by use. No enamel exists on the molars of the dugong and cachalot, nor on the teeth of the Edentata. In the Quadrumana, and in the Carnivora generally, as in Man, the cement is so thin over the enamel of the crown, as to be almost inappreciable; but it is thick in Herbivora, and especially so on the molars of the elephant, sloth, dugong, walrus, and cachalot. In the Ruminants, in most Rodentia, and in the Pachydermata, the enamel and the cement are arranged, within the crowns of the molar teeth, in double vertical plates or folds, between corresponding processes of the dentine, the variations in which form a means of classification in the Rodentia and Pachydermata.

When one of these compound teeth, such as a molar of the ox, deer, sheep, horse, or the still more complex grinder of the elephant, first cuts through the gum, the crown is covered with a thick layer of cement, which dips in between folds of enamel, which, in their turn, conceal variously-disposed plates of dentine. In the course of time, the cement on the grinding surface is worn down, and the folds of the subjacent enamel become visible. With further attrition, the cement between the folds of enamel wears away faster than the enamel itself, and hence the broad surface presents ridges corresponding with the harder enamel, and furrows corresponding with the softer cement, an arrangement well adapted, like the roughened surface of a mill-stone, for the grinding of hard grain, woody fibre, or roots. As the process of wear extends, the summits or bent parts of the folds of enamel are also worn through, and the concealed plate of dentine is exposed; in this case, the most complex markings appear on the grinding surface, produced by the alternating and often tortuous bands of dentine, enamel, and cement.

When the mammalian teeth, whether simple or complex, are worn down to the fang, they generally, as in Man, loosen and fall out; for their growth is completed at a certain period, after which their pulps shrink, they become subject to wear or decay, and undergo little or no repair. A remarkable provision exists, however, for the preservation of the cutting edge of the chisel-like incisor teeth, characteristic of, and necessary to, the *gnawing* Rodentia. These teeth show a persistent growth; the fang is deeply implanted in the jaw, and remains hollow and open at the base, into which the persistent pulp extends. The so-called enamel organ, on the anterior wall of the socket, is also persistent. Fresh dentine is constantly being formed within, upon the pulp, and fresh enamel upon the anterior surface, by the enamel organ; whilst the unequal wear of the hard coating of enamel in front, and of the dentine behind, preserves, during the whole of life, the chisel-like edge. From the persistent growth of these peculiar teeth, it happens, that if one of them be drawn or accidentally lost, the opposing tooth being no longer worn down by use, continues to elongate, and, following its natural curve, attains an abnormal size and shape, and its point turns round, and even penetrates the opposite lip. The teeth of the armadilloes and sloths also grow continuously, on persistent pulps.

In many Mammalia, sex exercises a remarkable influence on the development of certain teeth. Thus, in the Quadrumana, especially in the anthropoid apes, the upper canine teeth, in the male, are more than twice the size of the same teeth in the female; the tusks of the boar and of the male elephant, and musk-deer, are larger than those of the female animals. In the dugong, which, an exception in Cetacea, has both temporary and permanent incisor teeth in the two jaws, the upper permanent incisors project beyond the gum, in the male; but in the female, the permanent incisors in both jaws remain concealed throughout life, their growth being arrested before they cut the gum. The asymmetrical tusk, the rudimentary and concealed condition of the opposite tooth of the male narwhal, and the hidden rudiments of both teeth in the female, already mentioned, also show the influence of sex.

This rudimentary condition of certain teeth is, however, sometimes independent of sex, but characterizes groups of animals. Thus in the ox tribe, although the temporary incisors appear above the gum in both jaws, the permanent incisors are not developed in the upper jaw, but remain in a rudimentary condition within the bone.

The four canine teeth also exist, in a rudimentary state, in all young Ruminants, though they never rise above the gum. In both jaws of the young whalebone whale, rudiments of teeth exist, which are never further developed.

Birds.—In *Birds* the horny coating of the edentulous jaws is developed in successive laminæ, from the tegumentary membrane covering those bones. In the parrots this horny coat is thick, and is formed and supported upon papillæ. The absence of teeth in birds is associated with the existence of a muscular stomach or gizzard.

Reptiles.—Of these animals the Saurians exhibit the most perfect dentition, then the Ophidians, whilst the Chelonia are edentulous, their jaws being covered with a thick and dense horn, variously modelled, so as to act in bruising or dividing the food, the jaws of the vegetable feeders being thick, and those of the carnivorous species sharp on their edges.

In the Reptiles which possess teeth, the number varies, but in existing species, it is never very small, being thirty in certain monitor lizards, and twenty-nine, the lowest known number in the Ophidian amphisbæna. The number is not so determinate, nor are individual teeth so specially characterized, as in the Mammalia. In the crocodiles, and in many lizards, the teeth are limited to the jaw-bones; but they exist also on the pterygoid bones in the roof of the mouth, in the iguana, and on the palatine and pterygoid bones, in most Ophidia. In many of the latter, teeth are absent from the intermaxillary bones. The jaw-teeth form single arches, excepting only in the cæcilia or blind-worm, in which the lower front teeth are arranged in a double row.

The typical form of the reptilian tooth is conical, but in a few species this is departed from. These conical teeth vary greatly in size, from the minute teeth of the blind-worm, to the powerful canine-like teeth of the crocodile. They are sometimes cylindrical, but more frequently compressed, or much flattened and blade-like, having sharply trenchant, or even serrated, margins. The surface is either smooth and polished, or longitudinally striated. In the iguanas, the crowns of the teeth are widely expanded, and their sides and margins curiously notched. The teeth are relatively longest in Serpents, and in the case of the *poison-teeth* or *fangs*, present a remarkable structure. These *poison-fangs* are strongly recurved, and contain a canal, opening at both ends on the anterior or convex aspect of the tooth, above, close to the gum, and below, a short distance from the point of the tooth. The secretion of the poison-gland, found at the side of the head, is conveyed by a duct, to the opening of the poison-canal near the base of the tooth. Into this the poison is forced by muscles which tighten the gland capsule and compress the gland; and thence it is conveyed through the opening, in front of the point of the tooth, into any wound. The poison-fangs are anchylosed, or fixed by osseous union, to the superior maxillary bones; but since, in the poisonous serpents, these bones are movable, the poison-teeth can either, as when at rest, lie flat upon the gum, or they can be brought into a vertical position, in the act of striking.

The teeth of Reptiles have a short undivided root, which is, for the most part, anchylosed to the bone on which it rests. In the crocodiles, however, the teeth are separate, and are lodged in deep sockets; in the black alligator, the front teeth are embedded in sockets, whilst the hinder ones are fitted into a continuous groove. In the serpents and geckos, the anchylosed teeth are fixed to the sides of shallow sockets, but in the chameleons and most lizards, to the inner surface of a single alveolar plate.

Reptilian teeth always contain dentine and cement, sometimes also enamel and true bone. In most Saurians, the enamel exists as a thin coating over the crowns. The presence in certain teeth, of bone, besides the cement covering the dentine, depends on the conversion of the base of the pulp into bone, as the tooth becomes anchylosed to the jaw. The microscopic structure of the dentine differs slightly from that of the dentine in Mammalia, its substance being traversed by canals communicating with the pulp-cavity. In the iguana the dentine is singularly inflected on its surface. In the poison-fang of the serpent the dentine is folded on itself, in front of the pulp-cavity, so as to form the poison-groove or canal; a longitudinal section of the tooth shows the tapering pulp-cavity behind the poison-canal; whilst a transverse section shows this canal surrounded by the dentine, coalescing in front of it, the pulp-cavity forming a crescentic fissure behind it.

As the teeth of Reptiles wear out and fall away, an almost unlimited succession of new ones replaces them throughout life, a process entirely different from the simple succession of temporary and permanent teeth in the Mammalia. The new tooth usually appears at the inner side of the base of the old one; but the poison-fangs of the serpents are replaced by new teeth, formed behind the old ones.

When, as is usual, the teeth are anchylosed to the jaw, the new tooth simply grows up on a papilla, and replaces the falling one; but in the alligators and crocodiles, in which the teeth are lodged in sockets, the new tooth, also formed on a papilla, gains access, by a process of absorption, to the interior of the old one, penetrates its pulp, grows up within it, raises it, and finally throws it off from its own summit. By this time, as seen in the gavial, another rudimentary tooth is formed, and proceeds to grow, in like manner, into its predecessor. The process of absorption resembles that of the fangs of the milk-teeth in Mammalia; and like that it has been incorrectly attributed to mechanical pressure; for the growing tooth is softer than the old one, which is being absorbed.

Amphibia.—Fine prehensile teeth are found on the upper jaw and palate bones of the frogs and salamanders, more seldom on the lower jaw also. In the toads, only palatal teeth are present. Teeth are absent in the proteus and siren.

Fishes.—The teeth of Fishes present extraordinary varieties, greater than those of any other Class. Their number is almost countless in the silurus, its allies, and in the pike; but they become fewer or wholly absent in the lower orders of fishes. The chimæræ have two teeth in the lower, and four in the upper jaw; the lepidosiren has only a single dental plate in each jaw, and two small teeth on the nasal bones; the tench has one tooth on the occiput, besides some on the pharyngeal bones; whilst the myxine and myxinoid fishes have a single tooth on the palate, meeting two dental plates upon the tongue. Lastly, in the syngnathus or pipe-fish, in the hippocampus, in the Lophobranchiate fishes, in the sturgeon, ammocete, and amphioxus, no teeth exist.

The shape of the teeth in fishes differs much. They are usually simple and conical; they are minute, numerous, and *villiform* in the perch; longer, *ciliiform* or *setiform*, often bifid or trifid; and rasp-like or *raduliform* on the back of the vomer in the pike. They are commonly cylindrical, but sometimes flattened into a lancet-like blade, either straight, curved, bent sideways, or even barbed. The base may be broad, as in the larger teeth of the pike, the lophius, and certain sharks; the edge is sometimes finely serrated, as in the sharks generally, or is notched, so as to divide the tooth into from two to five lobes. In other less-known fishes, they are short and blunt, cubical, or prismatic, with from four to six sides, and closely arranged in a sort of mosaic work, showing their convex or flattened summits over broad surfaces. These surfaces are well calculated for grinding seaweeds, and crushing shell-fish or corallines, as seen in the teeth of the scarus or wolf-fish, and the cuneiform dental plates of the parrot-fish, which truly masticate their food.

The teeth of Fishes, as already indicated, are by no means limited to the premaxillary and premandibular bones of the upper and lower jaws. In the sharks and rays, they are thus confined to the fore-part of the mouth; but in the carp, all the teeth are at the back of the mouth, supported on the pharyngeal and basi-occipital bones. The parrot-fish has teeth, both at the front and back of the mouth, *i. e.*, on the premaxillary and premandibular bones, and on the upper and lower pharyngeals. In most fishes, there are teeth, not only on the above-named bones, but also on other bones around the middle part of the mouth, as on the palate bones, vomer, hyoid bones, and branchial arches, sometimes on the pterygoid, sphenoid, and nasal bones, and, though rarely, on the true superior maxillæ. Teeth are found in the median line, on the palate of the myxines, and even, in a few cases, on the symphysis of the jaw, a position not observed in any other Vertebrata. In the lampreys, most of the teeth are placed on the lips.

The teeth of Fishes are usually anchylosed to the bone on which they rest, the dental and osseus tissues being blended; occasionally it is the side of the tooth, and not the base, which is thus fixed. In certain Cartilaginous fishes, some of the teeth are divided at their base, and are so attached by ligaments, as to allow the teeth to be bent backward, in the mouth, by casual pressure; but when this is removed, the teeth spring up again. Even the anchylosed teeth are first attached by ligament only. A few examples are met with of the teeth being embedded in sockets; but then also anchylosis exists. The short strong teeth, which almost pave the mouth of the wolf-fish, are anchylosed to special eminences.

The teeth of Fishes are almost invariably composed of some kind of dentine only, the enamel and cement being absent. In certain cases, as in the carp, the tooth-substance is brown and semi-transparent; in the Cyclostomata, it has been differently described as dense, albuminoid, or horny; the labial teeth of certain goniodonts and chætodonts are flexible and elastic. The true *dentine* of fishes' teeth is very compact, especially on the surface of the tooth, where it occupies the place of enamel; this superficial layer has been called *vitro-dentine*. Another modification of dentine commonly found in fishes' teeth, is named *osteo-dentine*, because it contains vascular canals, resembling the Haversian canals of bone, between which are dentinal tubuli, no longer minute and parallel, but large, divided, and ramified. The so-called *vaso-dentine* is also found in the teeth of fishes, and, though more rarely, the *plici-dentine*, *labyrintho-dentine*, and *dendro-dentine*, so called from the *folded*, *wavy*, or *dendritic* appearances seen in them on section. Although teeth consisting of dentine alone, are only found in fishes, yet the most complex known teeth are met with in this Class. Thus, in the wolf-fishes, and diodons, the teeth contain dentine, osteo-dentine, enamel, and cement; and in the parrot-fishes, each pharyngeal tooth is composed of non-vascular dentine, covered by an enamel, anchylosed to the bone by vaso- or osteo-dentine, and fixed to the neighboring teeth, in the same row, by intermediate cement.

The teeth of Fishes, besides being liable to be accidentally torn off at their bases, are shed not merely once, as in Mammalia, but many times during life. In the pike and other common fishes, and in the Cartilaginous fishes, as the sharks, the formidable teeth are renewed and continually advance into place from behind, as the old ones break, or fall out. A few quite exceptional examples of strictly permanent teeth are met with, as in the lepidosiren and chimera.*

The Jaws and their Muscles.

The oral aperture of the Vertebrata, is a transverse opening, provided with jaws, one or both of which move *vertically*. In the Cyclostome fishes, the mouth, however, is *circular;* and, in the amphioxus, oval and longitudinal.

The form and strength of the jaws, the mode of articulation and motions of the lower jaw, or of both jaws, and the corresponding muscular apparatus, vary with the habits and food of the different Vertebrata.

In all the *Mammalia*, as in Man, the upper jaw is fixed to the bones above and behind it, and has no independent motion; whilst the lower jaw is movably articulated to the under side of the temporal bones, and is raised, moved horizontally, or depressed, by muscles exactly similar to those found in the human body.

In the large Carnivorous mammalia, however, the glenoid fossæ are not shallow, as in Man, but deep, narrow, and form long channels running from side to side, and inclining backwards and inwards towards each other. As the condyles of the lower jaw are equally narrow and elongated transversely, the motions of the jaw are limited to an up and down motion, in which not

* See the article "Teeth," by Professor Owen, Cyclop. Anat. and Phys., from which the preceding account of the teeth in the Vertebrata is chiefly derived.

only is a general, firm hold secured, but the notched edges of the laterally compressed molars pass close by each other, like those of the blades of scissors. In Insectivorous mammalia the motions of the jaws are almost equally limited. In the Rodentia, besides shutting powerfully in gnawing, the jaw executes rapid backward and forward movements, *across* the ridges of their molar teeth, so as easily to grind tough vegetable substances. In the Herbivora, the lower jaw is not limited to an up and down movement only, as in the Carnivora, nor to that and a superadded backward and forward movement, as in the Rodentia, but it is also capable of great lateral play. To permit this, the glenoid fossæ are wide and shallow, the condyles of the lower jaw are short, obtuse, and scarcely prominent, and the pterygoid muscles, which chiefly execute the lateral motions, are very large. The lower jaw is carried, during mastication, in a sort of circular sweep, beneath the upper jaw, first forward and to one side, and then backward and to the other, and so on, as may be readily noticed in the cow, when chewing the cud; the broad molar teeth, with their unequal ridges and furrows of enamel and cement, are thus most effectually employed. In the edentulous ant-eater and ornithorhynchus, the condyles of the jaws, and the glenoid fossæ, are only slightly developed, and the movements are comparatively simple and feeble.

In *Birds*, the actions of the jaws are prehensile and not masticatory, excepting perhaps in the parrots, in which there is a lateral motion. For the most part, the motion is hinge-like, and not very powerful, excepting in the strong-billed birds, such as the finches, rooks, toucans, and Raptores, which latter hold and tear their food by movements of the head and neck.

In *Reptiles*, whether they live on animal or vegetable food, the jaws are also prehensile, or incisive, rather than masticatory, except in the herbivorous iguanas, the molar teeth of which are large and tuberculated. In *Amphibia*, the jaws are weak, and snapping or suctorial.

In *Fishes*, the movements of the jaws are, likewise, for the most part, simply of a snapping and prehensile or incisive character; but the pharyngeal and other dentigerous bones within the mouth, are also movable, and these bones, as well as the jaws, especially in the parrot- and wolf-fishes, are provided with strong masticating muscles, which make them act powerfully against each other.

Denticles of the Non-Vertebrate Animals.

As already stated, true teeth are found only in the Vertebrata, but denticular organs are met with in some of the other Subkingdoms. Amongst the Mollusca, the Cephalopods are provided with horny jaws, which open and shut vertically. Some Gasteropods, also, have similar, but smaller, jaws moving laterally; but nearly all of them are provided with a peculiar strap-shaped band, beset with rows of minute horny denticles situated in the mouth, and often spoken of as the *tongue*. This organ, named by Huxley the *odontophore*, is placed not on the floor, but on the roof, of the mouth. It is moved backwards and forwards by appropriate muscles, and thus files or rasps very hard substances; as its anterior part is worn away, the odontophore, with its horny denticles, is renewed within a special sac, seen at its hinder end.

Amongst the *Annulosa*, the Arthropoda have mandibles, always found at the sides of the mouth, and provided with strong muscles, which give them a *horizontal*, not a vertical motion; they are composed of calcareous or chitinous substance, and differ remarkably in shape, in different species, being usually curved and pointed, and having serrated or dentated edges; they are strong in the actively feeding larvæ, and also in most perfect Insects, as in wasps and beetles. In the Crustacea, the mandibles are very strong, and in certain species, as in the lobster, hard gastric tubercles, worked by powerful muscles, exist at the entrance of the stomach. Even amongst the soft Annelids a denticular apparatus exists, as seen in the leech, which, by means of three minute denticles, inflicts a tri-radiate wound.

Amongst the *Annuloida*, many of the minute Rotifera possess complex denticulated plates, which are worked transversely across the oral orifice. In the hard-shelled Echinodermata, a singular masticatory apparatus is found, which, in its perfect form, consists of five large flattened, calcified denticles, having their free edges surrounding the oral aperture; the outer borders of these denticles, very peculiar in form, are received into a framework, the whole structure, in its entire state, forming the *lantern of Aristotle;* powerful muscles act upon these denticles, which comminute, or triturate, the food.

No denticles exist in the Cœlenterata; minute denticular organs are seen in some of the stomatode Infusoria, but they are, of course, absent in the astomatous Protozoa.

The Salivary Glands, and Insalivation, in Animals.

Salivary glands, or glands opening into the mouth, exist in most animals. In the Mammalia, they are nearly always present, but differ much in number and size. In the higher Mammalia, they resemble the glands in Man, except that the submaxillary is unusually large, and, in the seals and cats, the sublingual gland appears to be wanting. In Herbivorous, the salivary glands are larger than in Carnivorous Mammalia, in harmony with the more bulky, often drier, and amylaceous character of the food. In the Ruminants, all the glands, but especially the parotids, are very large, and even supernumerary glands are found, as in the ox. In the ant-eater, the salivary apparatus is enormously developed; the glands cover the forepart of the neck, and, even reach to the chest; a special reservoir, or *salivary bladder*, exists beneath the mouth, in which the saliva is probably detained; when rendered viscid, by absorption of its fluid, it lubricates the tongue, and assists in catching ants. In the Cetacea generally, the salivary, like the lachrymal, glands are wanting, the fluid medium in which they live, and the animal nature of their diet, rendering saliva unnecessary; in the herbivorous dugong, however, the parotid glands exist, but not the sublingual.

In *Birds*, the salivary glands are small in the wading and web-footed species, which live upon soft animal food; whilst they are proportionally larger in the rapacious and granivorous species. The saliva of birds is chiefly used to lubricate their food. In the woodpeckers, these glands are large, and the viscid saliva assists the tongue in entangling insects. In the Chinese swallow, which builds the edible nests, the parotid gland is largely developed, and its secretion is used in making the nests.

Amongst *Reptiles*, large salivary or buccal glands, found in the Ophidia generally, but not in all species, beneath the gum, along the margins of both jaws, serve to lubricate their prey before it is swallowed. The poison-glands of the venomous species may perhaps be regarded as extraordinarily modified salivary or buccal glands. In the Chelonian and Saurian reptiles, the salivary apparatus consists chiefly of lingual glands. In the chameleon, these are found in the enlarged extremity of its singularly formed insect-catching tongue, and secrete the slimy mucus with which it is covered.

In the *Amphibia*, similar glands are found, which, in the toad, serve a like office.

In *Fishes*, no salivary glands exist.

In the *Mollusca*, glands opening into the mouth, or into the commencement of the gullet, and therefore presumably salivary, exist in nearly all Cephalopods, Pteropods, and Gasteropods, varying in form and size, according to the construction of the mouth, and the nature of the food.

Amongst the *Annulosa*, glands, always regarded as salivary, exist in well-marked, but most variable forms, sometimes opening into the mouth, at the base of the mandibles, or beneath the proboscis, and sometimes further down near the stomach. These glands are, of course, minute and simple in structure, forming either short follicles, vesicles, blunt-ended tubes, long twisted tubes, as in all butterflies, and most beetles, or even branched tubes, as in Blaps. In the Myriapods, similar glands exist. In the Cirrhopods, they are of considerable size, and form the cement gland.

In the Annuloid Echinodermata, elongated cæcal tubes surround the œsophagus, and secrete a viscid fluid, which mixes with the food. Salivary tubuli have even been described in the Entozoa and Rotifera. No such glandular structures exist in the Cœlenterata. or Infusorial Protozoa.

The Pharynx and Gullet, and Deglutition in Animals.

The parts concerned in deglutition and the act itself, are similar in all the *air-breathing* Vertebrata, but both become gradually simplified. The uvula is absent, excepting in the higher Quadrumana. The soft palate is very large in the elephant and the Cetacea. Tonsils are always present. In all cases, from the highest Mammalia down to the Amphibia, the pharynx communicates with the cavities of the mouth, larynx, and œsophagus, and also, on each side, with the tympanum. In Mammalia, the structure of its walls resembles that in Man, and in the second stage of deglutition, it rapidly and safely transmits the food and drink into the œsophagus, over the laryngeal opening, whilst the third or œsophageal stage of deglutition is also, as in Man, performed more slowly by waves of peristaltic contraction, even against gravity, as is seen in the horse when drinking. In *Birds* and *Reptiles*, the pharynx is of simpler construction and action, being in the Serpents enormously dilatable. In the *Amphibia*, it approaches the less defined character which it presents in Fishes.

In *Fishes*, which respire in the water by gills, the pharynx has no communication with the nasal fossæ, and, moreover, the larynx and air-breathing apparatus are absent, except, in some cases, the air-bladder; hence the pharynx forms a mere infundibular passage, leading from the mouth into the shut œsophagus; but its sides are supported by the cartilaginous or bony framework of the branchial arches, between which are the branchial openings; besides this, there are special pharyngeal bones, which, as already mentioned, often bear prehensile or even masticatory teeth.

In the Molluscous, Annulose, and still lower Classes, a special pharynx is seldom distinguishable; but the buccal cavity usually passes directly into the œsophagus. In the Molluscoida, however, a part called the pharynx exists between the mouth and the œsophagus.

A true pharynx is indeed characteristic of the Vertebrata, and is specially developed in those which respire air, and in which the food has to be swallowed, without entering the sensitive air-passages, and with but a momentary interruption to the breath. In the cold-blooded Serpents, however, which swallow animals entire, deglutition is painfully slow, and causes a certain interference with respiration. In the young kangaroo, whilst it is still retained in the marsupium or abdominal pouch, the upper part of the larynx is elongated, and projects, as in the Cetacea, into the posterior nares, so that the milk passes down on each side, without risk of entering the air-passage, and without interference with the act of breathing.

The Stomach and Intestines in Animals.

Mammalia.—In the Quadrumana, the stomach often resembles that of Man, but it is sometimes globular or elongated, sacculated, constricted, or bent on itself; a cardiac and a pyloric portion are always recognizable. In the Carnivora, the stomach also presents the human shape, but the cardiac pouch is large. In the insectivorous Cheiroptera, it is globular; in the vampyres, it is long and conical, the cardiac end being the larger; in the frugivorous species it is still longer, the cardiac pouch is constricted in its middle, and the pyloric portion is bent. In the proper Insectivora, this organ is elongated. In the Edentata, it is usually simple; but in the genus Manis, the cardiac and pyloric portions are marked off by an internal fold, and, in one species, a long sac extends from the pyloric portion. In the sloths, the stomach is first divided into a cardiac pouch and a pyloric portion; the former has a dense epithelium, and is again subdivided into two parts, one ending in a blind canal; the pyloric portion has thick walls, and a soft mucous membrane, and is subdivided into two parts, which might be compared with the third and fourth stomachs of the Ruminants. In the ant-eaters, the cardiac part of the stomach constitutes a kind of *crop*, whilst a second chamber, having thick walls and a hard gristly lining, somewhat resembles the *gizzard* of the bird, and, compensating for the want of teeth, crushes the ants, by aid of the sand swallowed with them.

It is in the Ruminants, however, which are all vegetable feeders, that the stomach presents the most remarkable complication, being divided into four distinct cavities: first, the *paunch*, *rumen*, *ingluvies*, or *panse;* secondly, the *honeycomb*, *water-bag*, *reticulum*, or *bonnet;* thirdly, the *omasum*, *manyplies*, *psalterium*, or *feuillet;* and, fourthly, the *abomasum*, *reed*, *rennet*, or *caillet.* The *first* stomach, or *paunch*, is the largest, sometimes attaining enormous dimensions; it forms a bag, constricted at one point, and placed to the left of the œsophagus, which opens into its right upper end; its mucous membrane is papillated, and covered with a dense white squamous epithelium. In the camel tribe, two clusters of diverticula, or cells, exist, one on each side of the paunch. In the dromedary, each cluster is eighteen inches long and six inches broad. The component cells, quadrangular, and arranged in rows, are, when distended, about three inches wide and deep; their orifices are closed by membrano-muscular folds; some are subdivided by membranous ridges into secondary cells. These *water-cells* of the paunch are intended for storing up water, which is found only at long distances in arid countries. They are emptied by the action of their muscular walls.

The *second* stomach, or *honeycomb*, much smaller than the paunch, forms a simple bag beneath the œsophagus, between the paunch and the third stomach or manyplies. Along the inner surface of its upper concave border, is a peculiar *demi-canal* or groove, named the *œsophageal groove*, which runs from the *right* half of the œsophagus, of which it seems a continuation, on into the manyplies; its borders, composed of the muscular, submucous, and mucous coats, are much elevated, and can be brought together, so as to form a tube leading directly from the œsophagus, past the paunch and honeycomb, into the manyplies. The interior of the honeycomb is characterized by a cell-like or reticular structure, being developed into numerous polygonal cells, which are shallow in the reindeer and giraffe, deeper in the ox and sheep, and still more capacious in the llamas and camels. The mucous membrane, in the horned species, is papillated, especially on the interalveolar ridges. The cells of the honeycomb or water-bag retain water, which during digestion is mixed with the food. They are not proper water reservoirs, like the cells of the camel's paunch; for, unlike these, they have no marginal covering folds, are always open, are more subdivided internally, and do not, when filled, bulge on the outer surface. Moreover, the cells of the honeycomb are present in all Ruminants, whilst those of the paunch exist only in the camels, dromedaries, and llamas.

The *third* stomach, or *manyplies*, is usually the smallest cavity of the complex ruminant stomach; but in the camels it is larger than the honeycomb. It forms a sac, placed between the honeycomb and the fourth stomach, or rennet-bag; it communicates with the former, by a narrow passage, but opens quite freely into the latter. Its inner surface is remarkably increased by numerous longitudinal laminæ or folds, having their free edges turned towards the cavity, varying alternately in depth, and numbering from forty, in the sheep, to twice that number, in the ox; their resemblance to the leaves of a book, has given rise to the appellations manyplies, psalterium (psalter), and feuillet. The mucous membrane of the manyplies is villous.

The *fourth* stomach, or *rennet-bag*, from which, in the calf, the rennet is procured for curdling milk in the manufacture of cheese, is about one-third of the size of the paunch; it is elongated and conical in form, being wider at the left end next to the manyplies, and gradually narrowing towards the pylorus, near which the muscular coat is thickened, and where a circular pyloric valve exists. The mucous membrane, thrown into loose, irregular, longitudinal rugæ, connected by smaller transverse ones, is soft, destitute of villi, and highly vascular. It is chiefly composed of the countless gastric follicles, which open upon its surface. The rennet-bag is the true digestive stomach, being the only part of the compound ruminant stomach which secretes gastric juice.

The ruminant animal, cropping its herbaceous food, first partially masticates and insalivates it, and then swallows it. Afterwards, the animal being at rest, the food, so swallowed, is returned into the mouth, where it is now remasticated and once more swallowed. This constitutes the act of *rumina-*

tion, characteristic of these animals. The crude food, when first swallowed, descends in largish masses, which force open the borders of the œsophageal groove, and so escape into the paunch. Water, doubtless, is conducted along that groove into the honeycomb, or so-called water-bag, but it also partly escapes between the margins of the groove, and so enters the paunch, where, in the camel tribe, it is received into the system of water-cells there situated.

The food, partially masticated and insalivated, lubricated with mucus, and mixed with water and the juices of the paunch, undergoes maceration in that cavity, and also probably enters the honeycomb, in which it is further watered. Now, moulded by muscular action into small masses or pellets, either in the cells of the honeycomb bag, or by the œsophageal groove itself, it is propelled into the œsophagus, and thence, by an anti-peristaltic action, into the mouth. The soft and small pellet is there deliberately remasticated and insalivated, and is thus reduced to a semifluid pulp, which again passes down the œsophagus, and the margins of the œsophageal groove being now closed by muscular contraction, so as to form a complete tube, the semifluid mass is this time transmitted into the third stomach, or manyplies, from which it cannot return. Here it is brought into contact with a large surface of mucous membrane, loses much fluid, and soluble saccharine and other substances, and is then passed on to the rennet-bag, for the digestion of the albuminoid matters.

The precise mode of action of the borders of the œsophageal groove and other parts, is not known. Some suppose that the animal conveys the food or drink, instinctively or voluntarily, either into the first or second stomach, or else into the third. But according to another view, the process is partly a reflex act, and partly mechanical. In every act of deglutition, the borders of the œsophageal groove are believed to be approximated by a co-ordinated muscular act. When the food or fluid swallowed is large in mass or quantity, it is supposed to overcome the muscular action, and so to pass, if solid, into the paunch, and, if fluid, partly also into the honeycomb; but if the material swallowed be semifluid or fluid, and in moderate quantity, it is suggested that it may be conveyed along the temporary tube into the manyplies (Flourens). In the act of sucking, the milk is said to pass at once into this cavity, on account of the small quantity swallowed at a time. It is not certain whether the regurgitated pellets are moulded in the cells of the honeycomb bag itself, or in the œsophageal groove; nor whether the pellet is introduced into the lower end of the œsophagus, by the contraction of the sides of the groove, or by that of the reticulum itself. Though reflex, and probably excited by the food as a stimulus, and, therefore, not volitional, these movements of the ruminant stomach and œsophagus may be in some extent controllable by the will.

In the Pachydermata, the stomach is more simple. Thus, it is elongated, and possesses a long cardiac pouch in the elephant and rhinoceros, but in the former, it presents numerous internal transverse folds. The hippopotamus has two cardiac pouches, opening widely into the rest of the stomach; in the tapir and hyrax, this organ forms two cavities. In the pig the stomach resembles externally that of Man, though the cardiac end is more projecting, and a considerable extent of the lining membrane, near the œsophageal opening, is covered with a thick epithelium. In the peccary, still more of the cardiac portion is lined by a dense epithelium.

In the Solipeds, the stomach is rounder, the œsophageal and pyloric openings are near to each other, and the cardiac portion of the organ is lined by a thick epithelium, which terminates by a dentated margin.

In the Rodentia, the stomach is also marked off into a cardiac and pyloric portion, often indicated by an external constriction; the cardiac part is lined by a thick epithelium, and the pyloric end by a soft, glandular, mucous membrane. In the beavers, and some other species, the stomach has glandular crypts and cæca, the use of which is not known.

The Marsupials, whether carnivorous or herbivorous, have usually a simple somewhat elongated stomach, sometimes provided, like that of the beaver, with numerous crypts. In the kangaroo, the stomach is of remarkable length, being as long as the body; its middle portion is sacculated, and marked by three longitudinal muscular bands, somewhat like the colon; it has three compartments, two being cardiac pouches, and also three rows of large crypts along the bands.

It is remarkable that the carnivorous Cetacea have a more complex stomach than the herbivorous species. In the dugong, amongst the latter, this organ is elongated, and marked off into a cardiac and a pyloric portion, by a constriction, from near which two blind pouches proceed; the cardiac pouch presents a large glandular surface. The carnivorous cetacean stomach possesses from three to seven cavities, the first of which has a thicker epithelium than the rest.

On taking a general view of the above described modifications of the mammalian stomach, it would seem that, in its simplest form, it is a specially dilated part of the alimentary canal, distinguished by its abundant glandular tubules; this becomes elongated and narrower at a certain part, next constricted, and then partially subdivided within, by internal folds. These subdivisions in the complex stomach become still more pronounced, and associated with important differences of structure in the various coats, especially in the lining membrane. The pyloric portion of even the simplest stomach has larger gastric glands than the cardiac portion; and, in the compound stomachs, this part alone presents gastric tubuli, and secretes gastric juice. The cardiac end, variously subdivided and modified, is often lined by a thicker epithelium, and has been regarded as a dilatation of the œsophagus.

The *intestinal canal* is, in all *Mammalia*, marked off from the stomach by a circular muscular rim or pyloric valve. It presents even greater varieties than the gastric cavity, and these are more immediately referable to the nature of the food.

The most noticeable difference is in the relative length of the *intestines*, from the pylorus downwards, which are nearly always shorter in the flesh-feeding, and longer in the vegetable-feeding species, in every Order. The following Table illustrates both the rule and the exceptions:

Flesh-Feeders.		Vegetable-Feeders.	
Carnivora—		Ruminantia—	
Cat, dog,	5 to 1	Sheep,	30 to 1
Bear, hyena,	9 or 8 to 1	Solipeds—	
Seal,	15 to 1	Horse,	20 or 15 to 1
Insectivora,	6 or 3 to 1	Cheiroptera—	
Cheiroptera—		Frugivorous pteropus,	7 to 1
Insectivorous bats,	2 to 1	Quadrumana—	
		Omnivorous,	8 or 3 to 1

Excepting in the Cetacea, and a few Edentata and Cheiroptera, the subdivision into a small and large intestine prevails throughout. According to its length, the small intestine is more or less convoluted; it usually has internal valvulæ conniventes, and a villous mucous membrane; villi are always wanting in the large intestine. At the junction of the small with the large intestine, a more or less perfect ileo-cæcal valve is found, except in the Monotremata, Cetacea, and certain Edentata and Cheiroptera.

The colon is usually sacculated. A cæcum nearly always exists, its presence and size corresponding closely with the nature of the food, being either absent or small in flesh-feeders, and highly developed in vegetable-feeders. It is absent in all Insectivora and Cheiroptera, in some of the Edentata, and in certain Cetacea. In the Carnivora, generally, it is short and narrow, and is absent in the bears and weasels. It is present, and of variable length, in the Quadrumana. In all Ruminants it is capacious, but is still larger in the Solipeds, being, in the horse, three times as large as the stomach, and measuring two feet in length. In the Pachyderms, it is somewhat smaller, but the hyrax has two cæca. Amongst the Rodentia, the cæcum is absent in the insectivorous dormouse, short and small in the omnivorous rat; but it attains its greatest size, and is even marked by circular or spiral folds, in the herbivorous genera, as in the rabbit and hare, being, in the latter, eight times as capacious as the stomach. In the carnivorous Cetacea, there is usually no cæcum, but the balæna has a small one; in the herbivorous species, this part exists, being sometimes very large, but sometimes short and bifid. The carnivorous Marsupials have no cæcum, and the insectivorous species a small one; in the frugivorous species it is wide, and twice as long as the body, and in the herbivorous species three times as long.

The narrow part of the cæcum, the vermiform appendix, present in Man, exists in the apes and gibbons, and in the marsupial wombat, but in no other mammalian animal.

In the Monotremata, a small cæcum alone indicates the place of junction of the small and large intestine; the intestinal canal is narrow, but widens below, and ends in a cloaca, as in birds.

Birds.—The digestive canal in Birds is usually complex, the œsophagus being more or less dilated near its lower end, to form the *crop*, or *ingluvies*, to which succeeds the *proventriculus*, or proper secreting stomach; and beyond this is a third cavity, forming the *gizzard*. In the pelican, the floor of the mouth, and in some other birds, the sides of the fauces, are dilated into receptacles for food.

The *œsophagus* varies in length according to that of the neck. In the storks, herons, and pelicans, which swallow their prey whole, it is very wide; and in the cormorant, it forms a large pouch. It communicates freely with the proventriculus, and its longitudinally plicated mucous membrane has numerous follicles, which secrete a mucus to moisten the food, and aid in deglutition. The *crop*, or dilated portion of the œsophagus, is not distinct in the toucans and hornbills, or in frugivorous and insectivorous birds, or in most of the waders. It is even wanting amongst the swimming birds, in the swans and geese, but is small in the ducks. The large birds of prey have a small crop, lodged in front of the furcular bone or merrythought, at the root of the neck. The crop is most developed in the grain-eating gallinacea, forming a dependent bag connected with one side of the œsophagus, as in the fowl, or, as in the pigeons, consisting even of two lateral oval sacs. Where a crop exists, the short portion of the œsophagus below it is named the second or lower œsophagus; it gradually dilates into the proventriculus, which has no constricted cardiac orifice.

The *proventriculus*, also called the *ventriculus succenturiatus*, the true glandular stomach, varies in form and size in different birds, being sometimes wide and straight, and sometimes round. In the rasorial birds, it is wider than the œsophagus, but smaller than the gizzard; in the birds of prey, it is about the same size as the gizzard; in the parrots and storks, it is larger than the gizzard, and in the ostrich, four or five times as large. Its mucous membrane is thicker and more vascular than that of the œsophagus or even of the crop, and, as in the mammalian stomach, is provided with numerous gastric glands arranged perpendicularly to the surface, sometimes simply tubular, as in the carnivorous eagle and sea-gull, the insectivorous swallow, and the granivorous pigeon, and often sacculated, or even expanded into compound follicles, as in other grain-eaters, viz., the fowl, turkey, rhea, and ostrich. The disposition of these glands on the interior of the proventriculus, differs in different Orders, and even in different genera of the same Order. Thus, they may be diffused over the whole surface, or may form a single oval, elongated, or triangular cluster, two oval lateral clusters, or four arranged in a circular manner, or they may form a zone or belt.

The *gizzard*, *gigerium* or *ventriculus bulbosus*, the third, last, or *muscular stomach* of birds, is a more or less flattened, ovoid receptacle, having two neighboring apertures at its upper part; one, into which the proventriculus opens, and the other leading into the intestine. Between and below, as it were, these apertures, the gizzard forms a cul-de-sac, varying in size, and having walls of variable thickness in different species. In the birds of prey, the muscular coat is thin, and its fibres radiate from two lateral tendinous centres. It is in the rasorial and flat-billed swimming birds, as exemplified in the fowl and swan, that the gizzard is most developed; the deep red muscular fibres here form four very thick masses, two of which, named the *musculi laterales*, constitute the sides of the gizzard, whilst two smaller ones, the *musculi intermedii*, are placed at one end; they all radiate from, and towards, two very strong anterior and posterior tendons. The cavity of the gizzard is comparatively small, and is bounded by two flat surfaces, covered by a very thick, cuticular, horny, or even tuberculated lining membrane, supported on a dense, fibrous, submucous coat. The lining membrane is hardest in the granivorous birds, especially in those species in which the food is most solid; its density increases at the points where the pressure and friction are greatest. In the petrel, it presents a layer of small square tubercles, suggesting a likeness to the gastric denticles of certain Gasteropods. Hunter observed that in a sea-gull fed on barley, the muscles and cuticle of the gizzard became thicker than natural.

A pyloric valve usually exists in Birds; it is placed, in most species, a little below the gizzard, so that there is a short pyloric portion of the stomach intervening between the gizzard and the duodenum. The pyloric valve is very strong in some birds; it is double in the gannet, and, in the ostrich, forms six or seven ridges, which close the pylorus like a grating, permitting only small stones to pass.

The uses of the crop, proventriculus, and gizzard of Birds, are obvious. The crop, absent or small in birds living on fruit, insects, small aquatic animals, or flesh, but reaching its utmost development in those which feed on grain and other seeds, forms, like the ruminant paunch, a cavity for the retention and maceration, during several hours, of hard and dry food, so as to prepare it for the solvent action of the proper gastric juice of the proventriculus, and the grinding force of the gizzard. Seeds soften and swell under the influence of the scanty saliva, and of the more copious secretion of the crop. Pigeons will sometimes devour so many dry peas, as to be almost suffocated when these swell in the crop. The crop has been compared to the hopper of a mill, and the gizzard to the millstones, the former and larger cavity receiving the food, and delivering it, in successive suitable quantities, into the latter, which is so much smaller. Whilst rearing its young, the mucous membrane of the double crop of the pigeon becomes thicker and more vascular, its glands enlarge, and secrete a milky-looking fluid, which mixes with the softened grain in the crop, and is then, by an antiperistaltic action, regurgitated into the mouth, from which in the manner above described (p. 573), it is taken by the young pigeon, serving the same purpose as the lacteal secretion of the Mammalia. The proventriculus of Birds has been compared with the cardiac, and the gizzard with the pyloric, portion of the mammalian stomach. The secretion of the proventriculus has the same digestive properties as those of the gastric juice of Mammalia. The gizzard, which, when it exists, forms an internal masticatory organ, supplying the want of a masticatory apparatus in the head, has evidently a mechanical office. By the aid of pebbles, gravel, or sand, swallowed especially by granivorous birds, it triturates the food. Such birds do not thrive without a supply of pebbles or gravel; and pigeons have been known to carry these to their young. Grains of barley, inclosed in strong perforated tubes, pass through the alimentary canal of the bird undigested, whilst meat, similarly inclosed, is dissolved. Unbruised corn, with its hard silicious coat unbroken, is not soluble in gastric or intestinal juice. The gizzard of the ostrich can flatten metal tubes, pulverize glass balls, and break or blunt the points of needles and lancets, without injury to its hard internal coat. The grinding of the stones in a bird's gizzard may be heard by the stethoscope. The movements of the walls of this cavity are supposed to be slightly rotatory. In the membranous gizzard of the cuckoo, as I, as well as others, have found, the hairs of caterpillars are sometimes impacted in a regular spiral manner, as if felted by a continuous movement of partial rotation; balls of hairs spirally disposed have also been seen. These facts have been often quoted, in support of the view that, in all animals, intrinsic movements of the walls of the stomach may occur.

The intestine of Birds generally is, relatively to the body, shorter than that of Mammalia, but longer than that of Reptiles. It varies in length and width, as well as in the arrangement of the convolutions, and in the relative development of the cæca. In the birds of prey generally, the intestine is not more than twice as long as the body, including the bill, but in the osprey it is eight times as long. It is longer in frugivorous and granivorous birds, and shorter in the flesh-eating species. The duodenum always forms a long loop, embracing the pancreas. The remaining portion of the small intestine is variously folded in different birds, the convolutions being either spiral, concentric, or irregular. The mucous membrane is usually plicated. The distinction between small and large intestine now becomes less marked, there being no ileo-cæcal valve, and villi being found on the mucous membrane of both. Their place of junction is, however, frequently indicated by the presence of a cæcum, or rather of two cæca, for this diverticulum is most commonly double. The cæca are wanting in some vultures, in the cormorant, wryneck, and toucan, and in many carnivorous, insectivorous, and frugivorous birds; they are small and short in other vultures, in the eagles, and in the solan-goose, and also, when they exist, in the Insessorial tribes. They are longer in the nocturnal than in the diurnal birds of prey. Amongst the Rasores, they are short in the pigeons, but very long in the grouse, each measuring three feet, or thrice the length of the body, their internal surface being increased by eight longitudinal folds; in other Rasores, they are of moderate length. In the Cursorial birds, the intestinal canal, as well as other parts, approaches more nearly the mammalian character. The cæca, however, are absent in the cassowary, which obtains a constant supply of succulent vegetable food; whilst in the ostrich, which lives upon dry and scarce food, they are wide, about two feet long, and have an internal spiral fold, like that of the hare. In Birds generally, as in Mammalia, the cæca are absent, or small, when the food is concentrated and easily digestible; but when it is slower of digestion, or is taken in larger quantity, and at longer intervals, these appendages are most developed.

The large intestine beyond the cæca is long and mammalian-like in the ostrich, but usually is relatively short, straight, and not very wide; it terminates by an imperfectly valved circular opening in the dilated cavity called the cloaca, into which also the ureters and the duct or ducts of the reproductive organs open. In the hinder wall of the cloaca is situated the glandular organ known as the *bursa Fabricii.*

Lastly, there exists in many birds a short, narrow, blind diverticulum, connected with the *small* intestine; this is the vestige of the *vitelline duct*, which, in the embryo and young bird, connects the yolk sac with the intestine. It is called the *vitelline cæcum;* it has no special digestive function. A similar diverticulum is occasionally found in Mammalia, and even in Man.

Reptiles.—The alimentary canal in this Class is more simple than in Birds, to which, however, it approaches more nearly than to that of Fishes. The œsophagus varies in length, according to that of the neck; it is wide, plicated, and dilatable in the Ophidia; as in Birds, it joins the stomach without any constriction or cardiac orifice; but the mucous membrane suddenly ceases to have a dense epithelium, and becomes soft, smooth, and glandular. In the larger Saurians, the first part of the stomach has the form and structure of a gizzard, presenting thick muscular walls, the fibres of which radiate from two opposite central tendons; the pyloric part, more decidedly glandular, corresponds with the short portion sometimes found between the gizzard and the duodenum in Birds. In the Serpents, the cardiac part of the stomach is long, slightly saccular, and highly dilatable, whilst the pyloric portion is narrower and very muscular, being the only part like a gizzard. In the Chelonians, the stomach is curved, and larger at the cardiac than at the pyloric end. The pyloric valve is usually present in Reptiles, though not very distinct, and sometimes is scarcely recognizable.

The intestine in Reptiles is shorter and wider than in Birds. In the Saurians, there is mostly an ileo-colic valve; the crocodiles have no cæcum. In the Chelonians, the intestine is long and muscular; an ileo-cæcal valve usually exists, and also frequently a cæcum. In Serpents, the small intestine especially, is elongated; the ileo-colic valve is indistinct, or its place is indicated only by a change in the size of the canal; the large intestine sometimes has transverse folds in its interior, analogous with the spiral valve in the same part in Cartilaginous fishes. As shown by the form of certain reptilian *coprolites*, these folds must have been well developed in some extinct Saurians. The mucous membrane of the large, as well as of the small intestine, is plicated and villous. The lower end of the larger intestine forms a cloaca, receiving the ducts of the urinary and reproductive organs. The presence of a cæcum in certain Chelonia furnishes an additional example of the association of this organ with the use of a vegetable diet. The existence of a gizzard in some Reptiles, is one of the indications of the relations of this Class with Birds.

Amphibia.—The œsophagus of the Amphibia is short, dilatable, and muscular. The stomach is fish-like, being tubular, wider at the cardiac than at the pyloric end, and placed transversely, or curved upon itself. The intestine in the toad and frog is readily distinguishable into small and large, the former opening into the side of the latter; the ileo-cæcal valve is indistinct or absent. In the more fish-like Batrachia, the division into small and large intestine is imperceptible. The latter ends in a cloaca, which receives the ducts of the urinary and reproductive organs. The relation between the length of the intestinal canal and the nature of the food, is illustrated in the long and coiled intestine of the young vegetable-feeding tadpole, as compared with the short intestine of the insectivorous adult frog and toad.

Fishes.—In Fishes, the alimentary canal presents its most simple vertebrate form, being wide, and, in relation to the body, short. The œsophagus, short, wide, and muscular, sometimes passes so evenly into the stomach that the structure of the mucous membrane alone distinguishes them; in the former, it is pale and longitudinally plicated; in the latter, it is softer, redder, and full of gastric tubuli. In the Cyclostomata, it forms only a dilated portion of the nearly straight canal. In the Osseous fishes especially, it varies in size, but is usually tubular, bent once upon itself, and narrower towards the pylorus; sometimes, by protrusion of the convex border, and shortening of the concave border, it becomes flask-shaped or globular, with its cardiac and pyloric openings placed near together. The cardiac orifice, large, and sometimes provided with a valvular fold, not only readily permits the swallowing of the prey whole, but sometimes allows of regurgitation and rumination, the food being remasticated by the teeth, or by the pharyngeal bones, as seen in the carp. The pyloric part is sometimes so muscular as to resemble an imperfectly developed gizzard, having thick walls and a dense squamous epithelial lining. A pyloric valve nearly always exists.

The intestine is relatively short and wide, of nearly uniform diameter throughout, has few convolutions, and is distinguished into a large and small intestine, by a slight constriction only; there is no distinct ileo-colic valve, but sometimes a short cæcum exists. The small intestine has usually connected with it, immediately below the pylorus, the so-called *appendices pyloricæ*, which have been compared with the pancreas. The large intestine is often, as in the sharks, provided with internal folds or a spiral valve, by which its surface is much increased. It is also generally thrown into rugæ, which augment its surface. In some species, the intestine is unusually long; it is rarely supported upon a mesentery, excepting at a few points. The peritoneal cavity presents the unusual condition of opening directly on the exterior. In the singular amphioxus, the alimentary canal is short and nearly straight, the stomach being scarcely dilated; the intestine, as well as the mouth and sides of the pharynx, is provided throughout with cilia, which assist in moving on the fluids in the alimentary canal.

Mollusca.—In these animals, the alimentary canal, though simpler than in the Vertebrata, presents, as in them, many gradations, from a very complex form in the Cephalopods, to that of a slightly convoluted canal, with a simple dilatation for the stomach in the Lamellibranchiata. No distinction exists into small and large intestine.

In the Cephalopods, the œsophagus, which perforates the cephalic cartilage, is long, very dilatable, and ends in a strong gizzard, roundish or elongated in shape, lined with a hard epithelium, provided with two digastric muscles radiating from two lateral tendons, and having its cardiac and pyloric orifices near together. Sometimes, before entering the gizzard, the œsophagus expands into a crop. Below the pylorus, the intestine dilates to form a spherical, triangular, elongated, or spiral cavity, having a follicular mucous membrane; this has also been regarded as a stomach, but the ducts of the liver enter it through a sort of sac. Lower down, the intestine forms a simple, more or less curved, tube, which bends up, and opens into the branchial chamber, at the base of the mantle, not far from the mouth. The *ink-bag* is situated close to the lower portion of the intestine, and opens near it.

In the Pteropods, there are also, sometimes, found a crop and a distinct gizzard; the intestine presents three or four bends, surrounded by the liver.

In the Pulmo- and Branchio-gasteropods, the œsophagus is long, and frequently expands into a crop; the stomach itself often consists of two or more cavities; the first is usually lined with a thick epithelium, and is sometimes provided with hard internal laminæ or denticles, constituting a sort of gizzard, which is most developed when the buccal masticating organs are least so; the second has softer walls, and forms the true digestive stomach. The relative position of these triturating and digestive cavities is the reverse of that met with in birds. The intestine, more or less coiled, larger and more tortuous in the vegetable-feeders, and usually embedded in the liver, receives the hepatic ducts, bends once or twice, turns forwards, and ends near the forepart of the body, usually on the right side, but sometimes on the left, or even on the back. It is lined with a ciliated epithelium.

In the Lamellibranchiata, the transverse mouth is concealed in the mantle, the œsophagus is short, the stomach forms a simple dilatation, and the intestine is relatively simple, describing a few turns, and ending by a straight portion, opening at the hinder part of the mantle; its convolutions are embedded in the substance of the liver, and its terminal part is sometimes embraced by, or perforates, the heart. As already stated (p. 580), the direction of the principal bend of the intestine, whether to the dorsal or hæmal, or to the ventral or neural surface of the body, is characteristic in each Molluscous Class (Huxley).

Molluscoida.—In the Ascidioida and Brachiopoda, the alimentary canal is very simple, consisting either of a convoluted, or of a short recurved tube, merely dilated at the stomach, and having its terminal orifice approximated more or less to the often wide and valved mouth. In the Salpida, the outlet of the intestine is at the hinder end of the body. In some Brachiopoda the intestine ends in a blind sac, having no inferior aperture or outlet.

In the Polyzoa, the mouth, situated in the centre of the circlet of ciliated tentacles, leads into a wide pharynx, and short œsophagus, which terminates in a muscular stomach; from this, the intestine bends upwards again, and opens near the side of the œsophagus, close to the outer border of the tentacular circle. In some species, the stomach is muscular or gizzard-like. These creatures present one of the lowest types of animals possessed of a true alimentary canal, distinct from the walls of the body, shut off from the peri-visceral cavity, and having a distinct and permanent inlet and outlet.

Annulosa.—The alimentary canal here also presents marked degrees of complexity, from the highly developed apparatus found in certain insects, to the simple straight tube seen in the lowest Worms. The oral aperture or mouth, and the anal aperture or outlet, are always at opposite ends of the body. As a rule, the carnivorous kinds have a short intestine, and the vegetable-feeders a longer and even tortuous intestinal canal.

In the Insects, the alimentary canal varies with the stage of metamorphosis. In the vermiform larva, it is a straight tube, passing from one end of the body to the other; sooner or later, a dilatation appears, forming the stomach, which sometimes becomes divided transversely, and the œsophagus may also be further dilated into an ingluvies or crop. The intestinal canal presents cæca, and therefore a sort of distinction into small and large intestine. In the mandibulate Insects, as in the wasps and beetles, the crop is often glandular; the gizzard, which, unlike what occurs in Birds, is placed above the digesting stomach, has very muscular walls and a chitinous lining membrane, provided frequently with projections, laminæ, hairs, or denticles, but sometimes this part is indicated only by being a little more muscular. The true stomach has soft delicate walls, usually provided with numerous gastric follicles. Sometimes the stomach has no follicles, but its interior is laminated, or developed into cells, or into a few short cæcal tubes; sometimes it is quite smooth. The intestine is generally narrow, more or less convoluted, and seldom supported by a mesentery, but rather by the tracheæ; it sometimes presents dilatations or divisions, so as to imitate, perhaps in form only, the subdivision into a small and large intestine. Certain fine cæcal tubes communicating with it, are probably glandular structures rather than diverticula of the intestine. The first part is undoubtedly fitted for absorption, whilst the lower end is more excretory. It presents a terminal dilatation or cloaca, into which the reproductive organs open.

In the Myriapods, the alimentary canal is narrow and nearly straight, and is either, as in the carnivorous species, merely slightly dilated, to form a stomach, or, as in the vegetable-feeders, complicated by pairs of saccular projections, which have been regarded as crops, or gizzards, but may be merely glandular recesses. The intestine is straight, wide, plicated, and sometimes sacculated. Cæcal tubuli open into various parts of the alimentary canal.

In the Arachnida, the digestive tube is straight, very short, and comparatively simple. The stomach, scarcely dilated, has sometimes four appended sacculi, and sometimes cæcal prolongations, reaching into the bases of the palpi and legs. The intestine sometimes presents a globular dilatation, before it finally narrows.

Amongst the Crustacea, the higher forms, such as crabs and lobsters, possess a short wide sac, provided with internal hard calcareous, or chitinous denticles, which serve at once the purpose of a gullet, a masticatory apparatus, a stomach, and a gizzard. The denticles, arranged symmetrically around the canal, are worked by powerful muscles, and are shed when the animal changes its shell; besides the larger denticles, there are often stiff hairs, bristles, and horny ridges. The intestine, marked off by a constriction from this denticulated stomach, is short, nearly straight, and simple; it is sometimes subdivided by an imperfect valve, and, though seldom, has one or two cæca. In the lower parasitic Crustaceans, the alimentary canal is, however, straight and simple, becoming narrower as it passes backwards.

The shortness and simplicity of the alimentary canal in the Spiders, Scorpions, and Crustacea, which live, some upon the juices of other animals, and some on crushed animal food, compared with the length and complexity of the digestive tube in the vegetable-eating insect larvæ, or in the perfect beetles, further illustrates the modifications already noticed in the digestive canal of the higher animals, according to the nature of their food.

In the Annelida, the alimentary canal never presents any convolutions or bendings, and the mouth and outlet are always at opposite ends of the body. It has no mesentery. It is either quite simple, not even presenting a gastric dilatation, as in the lower marine species, or it is developed into simple tubuli, or subdivided pouches, or it may be regularly sacculated, as in the leeches, the blood sucked by those animals being retained, and slowly digested in the sacs. In the earth-worm, these sacs are represented by simple constrictions; it also has a sort of gizzard, and, within the intestine, a tubular cæcal organ, named the *typhlosole*, the use of which is not known.

Annuloida.—In the Rotiferous animalcules, the alimentary canal presents a pharyngeal dilatation, or crop, sometimes regarded as the stomach; the intestine is narrow and simple, opening sometimes at once on the surface, sometimes after forming a sort of cloaca; the orifice is usually near the hinder end of the body, on its dorsal aspect. In the Turbellaria, minute marine and freshwater worms, an alimentary canal is present, which is either simple, sacculated, or most remarkably ramified or dendritic; with few exceptions, such as the Nemertis and Microstoma, it has but one aperture, viz., a mouth, which is often provided with a disc-like sucker, for holding on to surfaces; the pharynx also has a proboscis, for sucking or boring purposes. Of the parasitic Scolecida, the Nematoida, or thread-worms, have an alimentary canal, with both inlet and outlet, a pharyngeal dilatation, and a simple intestinal tube, sometimes, however, dilated, so as to form a sort of stomach, and sometimes a second dilatation lower down. In the Trematoda or flukes, such as the distoma, tristoma, and others, there exists either a double or a ramified canal, with a common pharynx, but no anal aperture. In the Gordiacea, or hair-worms, there is likewise no such outlet. The organization of all parasites, to whatever class they belong, is more or less aberrant.

In the Tæniada or tape-worms, and in the Acanthocephala, represented by the echinorhynchus and echinococcus, also parasites living in the interior of other animals, there is no alimentary canal, nutriment being absorbed by them directly, through the integuments, from the digested food, or from the juices of the animal in which they live. In the tape-worms, straight tubes, with transverse or even radiating branches, exist, which are doubtless concerned in the nutritive processes, rather as circulatory and respiratory, than as digestive organs.

In the Echinodermata, the alimentary canal is well developed, distinct from the walls of the body, provided, in most cases, with openings at both extremities, and even supported by a mesenteric fold. In the Crinoida, the stomach and intestine are situated in the central part of the body, the latter opening at one side. Below the complex masticatory apparatus, elsewhere described (p. 581), the intestine of the Echinida, at first narrow, widens out, and presents a cæcal dilatation, beyond which the intestine coils twice round within the shell, reversing its direction in the latter half. In the Star-fishes, and also in the Ophiurida, the alimentary canal is very short, and gives off two ramified diverticula into each ray; the intestine opens by a minute orifice on the back; undigested matters are frequently discharged by the mouth. In the holothurida, the intestine describes a zigzag course; the outlet is placed at the higher end of the body.

Cœlenterata.—In this well-defined aquatic Subkingdom, there is no longer an alimentary canal, separate from the walls of the body, and provided with an oral and anal aperture. The digestive canal is very short and wide, and has but one external opening, the mouth, which, however, serves both for the ingestion of food, and the egestion of residual matters, and excretions; at its inner end, the digestive canal opens widely into the general cavity of the body. From this latter, numerous canaliculi are prolonged, in the medusæ, into the disc, some of them opening by pores in its margins. In certain ctenophorous forms, as in beroe, cydippe, and cæstum, the body cavity also opens, by one or two orifices or pores, at a point opposite to the oral aperture, but these are not intestinal or anal openings.

In the Actinozoa, the digestive canal projects a certain distance into the body cavity, which forms, outside that canal, the *perivisceral cavity.* In the Hydrozoa, the digestive canal becomes continuous, by a very wide opening, with the body cavity, without any portion of it projecting into that chamber; hence there is no surrounding or perivisceral chamber, and the outer surface of the continuous digestive and body cavities, are both in contact with the water. The hydra may be inverted, like the finger of a glove, and its outer surface, now become internal, will digest its food equally well.

In the compound Hydrozoa, the lower end of the body cavity of each polyp communicates, by a tubular process, with a common channel extending through the entire stem, a circulation of fluid, often containing granular particles, taking place through the whole colony. In the compound Actinozoa, the digestive cavities of the individual animals also open into a chamber in the common fleshy basis, the aperture being radiate in shape, and capable of being closed by muscular contraction.

Protozoa.—Of these, the higher Infusoria alone possess any representative of an alimentary canal. In the paramecium, for example, a depression exists on the surface of the body, bordered by cilia. and leading to an aperture called the mouth, from which a short blind tube, named the gullet, dips into the sarcodous body. This is the last imperfect trace of a digestive canal seen in the Animal Kingdom. Temporary cavities, formed by movements in the sarcode, into which food or coloring matters may penetrate, appear like stomachs, whence the name *polygastric* applied to some of those microscopic creatures; but as these cavities may be seen slowly to move within the sarcode, up one side, and down the other, they are no longer regarded as stomachs. The undigested food, after thus circulating through the sarcode, is expelled at a particular point, either near the mouth, or near the hinder end of the body, which point is only then recognizable.

In the Sponges, Rhizopods, and Gregarinida, no trace of an alimentary canal exists. The system of canals with incurrent and excurrent apertures, seen in the Spongida, is not digestive more than it is respiratory or reproductive, but depends on the plan of construction of Sponges, which are composed of an open framework, supporting aggregations of astomatous amœbiform masses of sarcode, each of which directly assimilates food. In the solitary amœba, and its allies, the proteiform contractile sarcode applies itself to nutrient substances, and completely incloses them; digestion and assimilation take place within it, and the undigested portions are extruded at some indifferent point. The Rhizopods are nourished in a similar manner. The microscopic parasitic Gregarinida, appear like the Tænia and Echinococci, to imbibe nutrient matter directly by their surface, from the fluids of the intestine, perivisceral cavity, or other chambers or tissues of the animal in which they live.

The Abdominal Digestive Glands.

Gastric Glands.—Gastric tubuli exist in the secreting portion of the stomachs of all the Vertebrata, becoming short and simple in the frogs and fishes. In the higher Mollusca and Annulosa, as in the Cephalopods, Pteropods, and perfect Insects, the stomach also has numerous follicles, probably analogous to gastric tubuli; but in the lower Mollusca and Annulosa, and in the Molluscoida and Annuloida, the walls of the gastric cavities are often destitute of distinct glands. This is the case also with the walls of the digestive canal in the Cœlenterata.

Liver.—This important organ, or some representative of it, is more widely distributed amongst animals than any other secreting or excreting gland. It is present as a well-defined organ, not only in all the Vertebrata, the amphioxus only excepted, but also in all the Mollusca and Molluscoida, and is represented in the Annulosa by tubular cæca or follicles, which are found even in the Annelida, and likewise in the Rotifera and Echinodermata amongst the Annuloida. No corresponding part, however, exists in those Annuloida which are destitute of a distinct alimentary canal, such as the Trematoda, Tæniada, and Acanthocephala, nor yet in the Cœlenterata, much less in the Protozoa.

Amongst the Vertebrata, the liver, proportionally to the body, becomes progressively larger in passing from the Mammal to the Fish. Its general form corresponds with that of the abdominal cavity: thus, it is broad in the apes and the Carnivora, longer in the larger Ruminant and long-bodied animals; of moderate length in Birds; broader in the comparatively short Chelonia and Sauria, but long in the elongated Ophidia; broad and short in the frogs and toads, but long in the newts; stretching widely into the abdomen of the broad-shaped skates and rays, but lengthened out in the eel. Its position is usually symmetrical, but in the Mammalia with large compound stomachs, it is placed more towards the right side, as is also the case in the anthropoid apes; in Fishes, generally, it lies more on the left side of the body. In Birds, in which the diaphragm is complete, the liver is notched for the reception of the heart and pericardium; in Reptiles, Amphibia, and Fishes, which have no diaphragm, the liver also reaches up to the pericardium, except when the body is very long, as in the serpents and eels.

The liver in the Mammalia generally, is nearly simple, its lobes being only slightly marked. In the Ruminants, it is subdivided into three lobes; in the Rodentia and Carnivora, there are from three to five lobes, viz., a central one, and one or two on each side; sometimes it is further subdivided into small and irregular secondary lobules. In the llama, amongst Ruminants, the under surface, and in the capromys, a Rodent animal, the whole surface, is divided by deep fissures into angular masses, resembling those of the kidneys of the bear. In Birds, the lobes are two, and symmetrical; in Reptiles and Amphibia, the lobes are also generally two, but the liver is undivided in the Ophidia; in Fishes, the liver is often more subdivided. The microscopic structure of this gland, in all the Vertebrata, resembles that of the human liver. In the curious amphioxus, a long cæcal appendage from the intestinal canal, having a layer of greenish cells lining its interior, is regarded as a rudimentary liver, no distinct organ otherwise existing.

In the *Mollusca*, the liver is a large, symmetrical, solid, and lobulated organ, having two ducts. Its great development in these animals, and also, it may be added, in the cold-blooded Vertebrata, may be connected with the function of storing up fatty matter, as the adipose tissue does in the higher Mammalia. The nucleated hepatic cells in the Non-vertebrate animals, and also in the cold-blooded Vertebrata, contain much more simple oleaginous matter than they do in the warm-blooded Vertebrata, in which latter the proper biliary fatty acids chiefly occupy the cells; in Birds, the cells contain less ordinary fat than in Mammals. Sometimes, as in the Cephalopods and Lamellibranchiata, the liver is subdivided into minute lobules, composed of branching ducts, ending in dilatations. In the Gasteropods, the ramified ducts and terminal follicles are more distinct, so as to form a loose compound racemose gland. The chief ducts are ciliated internally.

Amongst the Molluscoida, the Brachiopoda have a large, minutely lobulated liver, composed of ramified tubuli. As some of the earliest fossils yet discovered belong to this Class, an hepatic organ yielding bile, and, therefore, digestive processes corresponding with those known to us in the present day, must have existed in most remote periods of the earth's history. In the Ascidioida, the liver presents interesting gradations; for, in different cases, it may consist of a small gland, a cluster of follicles, a single follicle, or simple lacunæ or laminæ on the inner side of the intestine; it is represented only by a yellowish, orange-colored, or brownish glandular spot, on the *hepatic portion* of the walls of the intestine. In the Polyzoa, the sides of the intestine below the stomach are marked with brown hepatic tubes, follicles, or spots.

Amongst the *Annulosa*, the Crustacean liver is of a yellowish color, large and complex. In some kinds, as in squilla, it is symmetrical, lobulated, and sublobulated, each sublobule consisting of clusters of round follicles connected with a central duct. In the crabs and lobsters, the follicles of the liver are innumerable, much branched, and separated from each other. In the river crab, the follicles are less ramified. In the lowest Crustaceans, such as the parasitic argulus, the hepatic follicles are still more simple, or this organ consists only of a mass of nucleated cells.

In the highest Insects, and in the Myriapods, the liver is represented by hepatic tubuli, connected with the intestine; these are short and numerous in dytiscus, only two, but elongated, in blaps, or even single, as in the grasshoppers; sometimes they are mere vesicles. In no case is the liver massive, but always tubular. In the Spiders, the hepatic follicles are either short and simple, or they end in compact clusters of vesicles. In the Annelids, the liver is represented by gland cells, situated either in ramified tubes, as in Arenicola, or in tubuli ending in an oval sac, as in Aphrodita, or in numerous follicles, as in the leech.

Amongst the Annuloida, a single long follicle in the Trematode worms, represents the simplest form of rudimentary liver; in the parasitic Tæniada and Echinococci, the liver, as indeed the intestine itself, is unrepresented. In certain Echinodermata, as in asterias, colored cells are found in the walls of the radiating prolongations of the gastric cavity, which perhaps secrete biliary matter.

In the Cœlenterata, no separate hepatic organ exists in connection with the simple digestive cavity; but the walls of this, as in velella, sometimes present a mass of gland cells, which may form bile. No such product has yet been found in any part of the unicellular Protozoa.

Bloodvessels of the Liver.—In all the Vertebrata, the liver receives blood both from the hepatic artery and the portal vein. In the Mammalia, this vein, as in Man, has only a few communications with the lumbar and pelvic systemic veins. In Birds and Reptiles, the connection between the pelvic and portal veins is such, that a part of the blood from the lower extremities, and from the tail, joins the portal blood, and passes into the liver. In Fishes, the caudal veins, and sometimes those from the reproductive organs and the air-bladder, are connected with the portal system. In the Mollusca, the liver is supplied solely with arterial blood; the same is the case also in the Annulosa and Crustacea, indeed, in all Non-vertebrated animals which have bloodvessels.

Gall-bladder.—In Mammalia, a gall-bladder is sometimes present, and sometimes absent. Amongst the herbivorous kinds, it is present in nearly all Ruminants, as in oxen, sheep, goats, and antelopes, but not in the camels and stags. It is also absent in Solipeds and in most Pachydermata, as in the horse, tapir, peccary, and elephant, but not in the pig. In the elephant, the hepatic duct is dilated and thickened, and has a spiral fold within. The gall-bladder is wanting, in the mice and hamsters, amongst Rodentia; also in the sloths amongst the Edentata, and in the true Cetacea. In the carnivorous and insectivorous kinds, the gall-bladder is present. In the cat and a few other animals, it is sometimes double. When the gall-bladder is present, a cystic, hepatic, and common bile-duct exist.

In Birds, the gall-bladder is generally present, but is wanting in certain species of a particular genus, without obvious relation to its habits or food; it is absent in the ostrich, pigeons, toucans, and many parrots. Proceeding from the liver, in Birds, are two ducts, one hepatic, to the duodenum, the other to the gall-bladder, from which a cystic duct runs on to the duodenum; there is, therefore, no common bile-duct. When the gall-bladder is wanting, the two hepatic ducts open separately into the intestine.

In Reptiles, a gall-bladder always exists, but it varies in form. It is placed at a distance from the liver and has a long cystic duct, in the Ophidians; but it is embedded in the substance of that gland in the Chelonians. There either is a common bile-duct, or the cystic and hepatic ducts open separately into the duodenum.

The gall-bladder invariably exists in Amphibia.

In Fishes, this receptacle is usually present, though it is absent in many genera, being then replaced by a dilatation upon one of the hepatic ducts, which are here usually numerous.

In the Mollusca and Molluscoida, in which the liver is massive, no gall-bladder is found; nor could such a receptacle exist in connection with the hepatic tubuli of the Annulosa and Annuloida.

Pancreas.—This gland, or some representative of it, is present only in the Vertebrata, and in the higher Mollusca. It is not so widely distributed amongst animals as the liver; and, moreover, it much sooner assumes a rudimentary form, in the descending series, viz., in the Fishes.

In Mammalia, Birds, and Reptiles, the pancreas occupies the concavity of the constantly present curvature of the duodenum. In Mammalia, when the duodenal mesentery is short or absent, as in the Quadrumana, Carnivora, Ruminants, and Solipeds, the pancreas is compact and elongated, with a portion extending towards the spleen, so that it may seem bilobed, as in Carnivora and Ruminantia, or even trilobed, as in the horse, the splenic portion being double; when, however, the duodenum has a wide mesentery, as in Rodentia, the pancreas forms an arborescent mass between the two layers of the mesentery, as seen in the rabbit and rat.

The typical number of pancreatic ducts, in the Mammalia, appears to be two, as indeed is the case in the early condition in Man, the upper and larger duct alone persisting. In the horse and dog, there are also two ducts, the lower one being the larger; in the dog, this latter opens separately into the duodenum, but the upper one enters it close to the bile-duct. In the lion, two ducts join the bile-duct, and enter the duodenum by a common orifice. In the rabbit, the upper duct is very minute, and the chief duct opens from 9 to 12 inches below the pylorus. In all cases, however, the pancreatic fluid is discharged into the duodenum. In certain Carnivora, as in the seal, and sometimes in the cat, the chief duct dilates into a reservoir, previously to entering the intestine.

In Birds, the pancreas is proportionally larger than in other Vertebrata, in part, perhaps, owing to the deficiencies in the salivary glands. It usually consists of from two to six elongated portions, attached, as usual, to the much-bent duodenum. Each portion of the gland has a duct, generally opening separately into the intestine. There are six ducts in the vulture, fowl, heron, and grebe, three in the crow, pigeon, grouse, and duck, but only one in the eagle, quail, ostrich, and stork. In the stork alone, the single pancreatic duct opens, by a common orifice, with a single hepatic duct. Usually, one at least of the pancreatic ducts, in Birds, opens above the bile-duct, but this is not constant; when several pancreatic ducts exist, they usually open alternately with other hepatic or cystic ducts; the cystic duct generally opens lowest.

The bile and pancreatic juice must be speedily, and almost simultaneously, mixed with the food. In the ostrich, however, these secretions are mixed with the food at some distance apart, the bile escaping through the single hepatic duct, close to the pylorus, and the pancreatic juice also by a single duct, 3 feet lower down.

In Reptiles, the pancreas is usually large. It is larger in the herbivorous than in the carnivorous Saurians, being largest in the iguanas. In the Chelonians, this gland is even ramified, as it is in the Rodents. In the Ophidians, it is either long and bifid, pyramidal, or round. The duct is nearly always single, and generally enters the duodenum separately, but sometimes with the bile-duct. In the Serpents, the pancreas is joined to the spleen, and has even been confounded with it.

In the Amphibia, the pancreas is found in the mesentery, between the stomach and duodenum; it is smallest in the purely aquatic species, such as the tritons. In the frog, the bile-duct perforates the pancreas, and, it is believed, receives small pancreatic ducts in its course. In the lowest Amphibia, as in the siren, the pancreas is much subdivided, so as to approximate to the form of the pyloric appendages in the Fishes; its ducts are no longer united into one, or into a few principal trunks, but form numerous parallel canals, opening separately into the duodendum.

In many Fishes, there are found, opening into the duodenum, near the pylorus, certain simple tubular or ramified follicular prolongations of the coats of the intestine, lined by a glandular membrane, named the *pyloric appendages*. The food does not enter them, and, from their position and glandular character, they have usually been regarded as the homologues of the pancreas, but they are somewhat anomalous organs. In the sturgeon, these appendages are so numerous as not to have been counted; the cod and whiting have about 120, the salmon 60, averaging 6½ inches in length, the sprat 9, the perch 3, the turbot 2, and the ammodytes and polypterus only 1. They are entirely absent in many Orders. When few in number, they open separately into the intestine; but when numerous, they combine into clusters, each opening by a single orifice. Thus, 50 cæca, in the pilchard, open by 30, and in the tunny by only 5 orifices; in the swordfish, there are only two openings, and, in the sturgeon, the multitudinous cæca open by a single short duct. They are largest and most numerous in fishes of active digestion and rapid growth, and, on the whole, most developed in the more voracious tribes. They are more commonly few and large in the Osseous fishes, whilst in the Cartilaginous group they are usually smaller and numerous. When absent, the mucous membrane of the intestine below the pylorus is, sometimes, as in the eel, thick, vascular, and glandular, and yields, on pressure, a copious secretion.

The pyloric appendages are certainly glandular organs and not intestinal diverticula, intended for purposes of absorption; but it has been suggested that they are special glands, and that the true representative of the pancreas in Fishes, is a small gland sometimes found attached to the liver. Such an organ exists in the carp, pike, silurus, sturgeon, and ray, in which fish it is large and has a duct opening near the bile-ducts, and in many other species. In some instances, it would seem to be a detached portion of the liver, but in other cases, its pancreatic structure is undeniable. Certain fish, as, for example, the trout, possess this organ as well as the pyloric appendages; in others, it is very small; in some, it is not found, but may then be represented by glandular structures in the walls of the intestine. Bernard, who doubts the pancreatic character of the pyloric appendages, asserting that their secretion is acid and viscid, like the intestinal juice, and not alkaline and diffluent, like the pancreatic juice, states that a watery emulsion of the *proper* pancreas of the ray, converts starch into sugar, and decomposes fatty matters into their proper fatty acids and glycerin, like the secretion or substance of the pancreas of the higher Vertebrata.

In certain Cephalopods, a laminated and folliculated sac, connected with the two hepatic ducts, in other Cephalopods, a spiral appendage, and, in many Branchio-gasteropods, as in aplysia and doris, a long cæcal glandular tube, which communicates with the intestinal canal below the stomach, may represent a molluscan pancreas.

In the Annulosa, the Insects and some others, have tubuli, connected with the upper part of the intestines, which may be pancreatic. Similar rudimentary parts exist in the Rotifera, amongst the Annuloida. In cases in which such tubuli are not present, gland cells are sometimes found in patches upon the lining membrane of the intestine. Sometimes even these are not distinguishable.

Intestinal Glands.—In all the Vertebrata, besides structures resembling the closed sacs of the solitary and agminated glands, the intestinal tubuli or crypts of Lieberkühn exist. In Mammalia and Birds, and probably in Reptiles, Amphibia, and the higher Fishes, racemose mucous glands are found in the duodenum.

The tubular or saccular appendages, the short cæca, or the minute patches of glandular epithelial cells, distinguished by their color and contents, which are found in the Molluscous, Annulose, and lower allied forms, are probably not representatives of the intestinal tubuli in the higher animals, but rather of the liver and pancreas. Indeed, the intestinal canal is itself so minute in many of these lower animals, that its lining membrane is almost of necessity simple, smooth, and covered throughout with a delicate epithelium only.

The Chemical Processes of Digestion in Animals.

In studying the action of the digestive fluids, physiologists have employed not only the human secretions, but also, and sometimes exclusively, those collected from fistulæ in animals, and likewise artificial fluids made by macerating the glands in water. The properties of these several secretions having been established experimentally, in regard to *certain* vertebrate animals, it is reasonable to conclude that, wherever these particular glands exist, the respective secretions possess similar, if not identical, properties.

The *saliva* is most abundant in herbivorous and granivorous animals, in which the quantity of food to be moistened is greater, and the special action of this fluid on starchy matter is most required; in carnivorous and insectivorous creatures, this action is not necessary, and the secretion is less plentiful, being used rather for purposes of lubrication; or, as in Fishes, it may even be wanting. Nevertheless, the saliva of the dog, taken from the mouth, converts starch into sugar, though somewhat slowly. It is said, however, that the secretions of the parotid and submaxillary glands in the dog, and even of the parotid only, in the horse, are by themselves, and unmixed with the mucus of the mouth, incapable of effecting this transformation.

In those Mollusca, Annulosa, and Annuloida, in which, as in Cephalopoda, Insecta, Myriapoda, and Rotifera, glands, *called* salivary, exist, the exact properties of the secretion, and its chemical action on the food, have not yet been determined; but it is usual to regard those glands, whether tubular or follicular, which open into the upper part of the alimentary canal, as salivary glands. On similar grounds, gland structures opening into the stomach are considered as gastric glands; those connected with the upper part of the intestine, as hepatic, or hepatic and pancreatic; and, lastly, those emptying themselves into the lower part of the intestine, as excretory, and probably renal.

As albuminoid substances are essential to the formation of all animal tissues, the *gastric juice*, which acts upon them, would appear to be likewise an essential solvent in the digestive function of every animal. Hence, it is probably present in all animals, certainly in the lowest which possess a stomach, and even in the Cœlenterata. When no distinct gastric tubuli exist, the peptic agent is secreted by the cells of the lining membrane of the digestive cavity.

The stomachs of Fishes, after death, are often rapidly digested by their own gastric juice; whereas, this occurrence is much less frequent in Man and Mammalia. This has been referred to the small difference of temperature which takes place after death, in a fish, as compared with a warm-blooded animal. The gastric juice of fishes habitually acts at a low temperature; whilst that of the warm-blooded animal operates at a much higher temperature. It is said that the gastric juice of fishes loses its peptic properties at the ordinary temperature of a warm-blooded animal, and inversely, that the gastric juice of the warm-blooded animal acts slowly, or not at all, at the temperature of the fish; and, moreover, that the solvent powers of the gastric juice of a Mammal are not lost, until it has been heated to 120°; whilst in the case of the fish, they are lost at 80° (Brinton). If this be confirmed, it shows a remarkable modification of the properties of the same secretion, in different animals having particular conditions of existence. It would be interesting to note whether post-mortem digestion of the gastric cavity of the non-vertebrated animals ever takes place.

From its peculiar color, the *bile* can be easily recognized. It may thus be detected in those Annulose and Annuloid animals, even in the minute Rotifera, in which the liver is not massive, as it is in the Vertebrata, Mollusca, and higher Molluscoida, being represented only by hepatic tubuli; colored secretions are also detected in the gland cells of still lower animals. The office of the bile must be similar in all animals in which it is found.

The peculiar property of the *pancreatic juice*, that of emulsifying and decomposing fat, has been shown by Bernard to exist not only in Mammalia, but also in Birds, Reptiles, Amphibia, and Fishes, as, for example, in the goose, turtle, frog, salamander, and ray. Moreover, he asserts that, when the pure saliva, in any animal, is incapable of converting starch into sugar, the pancreatic fluid possesses this property.

The action of the *intestinal juice* upon food has been shown to be, in the higher animals, as in Man, supplementary to that of the other secretions. In the lower animal forms, in which the intestinal tubuli come to represent important glands, an analogous blending of function may prevail.

The organic food of all animals, whether derived from other animals or from plants, consists of similar proximate chemical substances; and the solution of these is probably accomplished, in all cases, by processes of a similar nature. But our knowledge of the specific chemical differences and modes of action of the digestive fluids in different animals, is yet imperfect. In the Mammalia, and perhaps in all Vertebrata, the composition and action of the fluids resemble those observed in man. The gastric juice of the herbivorous sheep and calf dissolves animal food, as readily as that of the omnivorous pig and carnivorous dog. But many modifications, yet undiscriminated by the chemist, doubtless exist, as illustrated by the ascertained varieties in the acids of the gastric juice and the bile, in certain Mammalia and Birds (pp. 531, 540). Still more important differences in composition and power may exist, especially in the lower tribes, in some or all of the digestive secretions, adapting them to the solution of substances ordinarily indigestible. Thus cellulose, lignin, and even resinoid bodies from the vegetable kingdom, and yellow elastic tissue, cartilage, and the horny, chitinous, and coriaceous integuments from the animal kingdom, are eaten and probably partially digested by certain insects and other creatures, though usually those substances resist digestion.

In the complex alimentary canal and glandular appendages of the Vertebrata, Mollusca, and Annulosa, in the more simple digestive system of a polyzoon, or of a rotiferous animalcule, and even in the digestive cavity of the hydra, with its single external opening, its communication with the cavity of the body, and its want of distinct glandular appendages, the digestive secretions are always produced by glandular epithelial cells, whence they are discharged into the alimentary canal, at suitable points, to act upon the food. In the absence of massive or tubular glands, or of clusters of special cells, it is even possible that adjacent cells, nearly or quite similar under the microscope, may perform the office of different glands. Digestion, in the hydra, may be as complex a process, regard being had to the chemical composition of its food, as in the highest Vertebrata. So long, indeed, as we recognize in any animal a distinct digestive cavity, we may reasonably infer the occurrence of a digestive process, rendering different nutrient substances soluble and absorbable. The starchy, albuminoid, fatty, and the less digestible substances used as food, must require their peculiar transmuting, liquefying, or emulsifying solvents, produced in infinitesimal quantity, but acting with characteristic power. It is observable, however, that of these fluids, the peptic and emulsifying agents are the most essential, specific, and universal: for in the cold-blooded aquatic animals, whether vertebrate or non-vertebrate, such as the voracious Fishes, and the carnivorous Mollusca and Cœlenterata, there is little or no necessity for a salivary fluid capable of transmuting starch; whilst even in the lowest animals, fatty and albuminoid substances are essential constituents alike of the bodies and of the food. The low temperature of these animals, and the higher temperature of the starch-feeders generally, are interesting facts, in connection with the heat-producing power of amylaceous diet.

In the unicellular Protozoa, whether, as in the Infusoria, there exist a short tube leading into their interior, or as in the Sponges and Rhizopods, no digestive cavity at all, solid food must also be dissolved by some action of the animal, before it is absorbed; though these universally aquatic creatures may be partly nourished by materials already dissolved in the surrounding medium.

In the case of the parasitic Gregarinida, and even of certain of the annuloid Entozoa found in the alimentary canal of other animals, the nutrient substances absorbed are probably those which have already been digested, and so prepared for absorption by the gastric and other secretions of those animals, a sort of vicarious digestion being here employed. In those Entozoa, however, which infest other organs or tissues, such as the air-tubes, muscles, brain, and interior of the eyeball or bloodvessels, probably little or no digestive change of the nutrient materials is required; the nutritive function consists merely of imbibition and assimilation, observed in the ultimate nutritive processes in the higher animals, and digestion is merged in nutritive absorption.

ABSORPTION.

By the process of digestion, the food is reduced to a compound alimentary basis, composed of aqueous, saline, extractive, mucilaginous, saccharine, amylaceous, oleaginous, and albuminous matters, sometimes mixed with alcoholic, ethereal, acid, pungent, odoriferous, and coloring substances. The materials of this complex pabulum, whilst retained within the digestive cavity, remain, strictly speaking, *external* to the living frame; but a process immediately ensues, by which they are, sooner or later, taken up into, and enter the living tissues; this is termed *Absorption.* The chief object of this process of the *absorption of food*, is the introduction of new material, for the repair of the continuous waste of the living body.

Absorption, however, considered as a physiological function, consists of more than the mere taking up of nutrient materials from the interior of an alimentary canal, or of a simple digestive cavity, or at the surface of a unicellular animal organism. It includes that general process by which all external soluble substances, whether solid, fluid, or gaseous, beneficial or poisonous, nutrient, stimulant, or respiratory, are introduced into the tissues of the body, through any natural or artificial surface whatever. Moreover, it comprehends, in part at least, another process, by means of which portions of the living tissues are themselves removed, or absorbed, within the body. The former of these two processes is sometimes named *general absorption*, and the latter, *intrinsic* or *interstitial* absorption. Intrinsic absorption is essentially a nutritive process. The term extrinsic may be applied both to general absorption and to the absorption of food.

The Absorbent Vessels and Glands.

In Man, and the Vertebrata generally, two sets of vessels are engaged in the processes of absorption, viz., first, certain *bloodvessels*, especially the *venous capillaries*, and the *smaller veins;* and, secondly, the *absorbent* vessels proper.

Fig. 100.

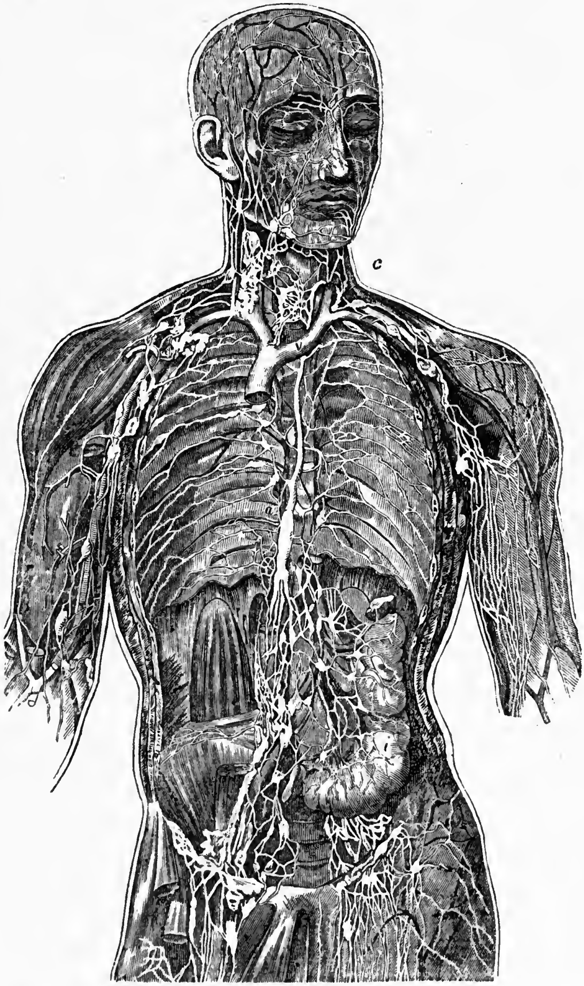


Fig. 100. General view of the principal absorbent or lymphatic vessels and glands. The superficial lymphatics are shown on the head and face, and on the left limbs; the deep lymphatics on the right limbs. The lymphatic glands are seen in the neck and axillæ, at the elbow, in the groins, pelvis, and abdomen; a part of the small intestine, *i*, shows its chief lymphatic or lacteal trunks, passing on to the mesentery, through the mesenteric glands, to the upper and back part of the abdomen. *a*, the chief trunk of the absorbent system, named the thoracic duct, commencing below, in a dilatation, named the *receptaculum chyli*, and curving down in the neck at *c*, to end in the great veins at the root of the neck, where the jugular and subclavian veins join to form the left innominate vein, *v*. On the right side of the neck, smaller lymphatic trunks are seen entering the great veins.

The absorbents of the body generally, which always convey the transparent *lymph*, and are named the *lymphatics*, commence, by networks, near the various membranous surfaces, and in the interior of certain tissues and organs. Their number, in any part, seems to be proportionate to the quantity of areolar tissue which it contains, rather than to the number of its bloodvessels, or the activity of its functions; thus, lymphatics have not been found in the brain and spinal cord, and only a few in the muscles; but in the subcutaneous areolar tissue, and the intercellular spaces, they are very abundant. They are numerous in the serous and synovial membranes, but still more so on the mucous membranes and skin. The trunks from the commencing lymphatic networks (Fig. 100), either proceed in company with the bloodvessels, thus forming the *deep lymphatics*, or else run on the *surface* of organs, or in the subcutaneous cellular tissue of the body and limbs, so forming the *superficial lymphatics*. From all parts of the body, they run towards the root of the neck, where they end in the venous system. More numerous than the bloodvessels, they pursue an irregular course, often unite and again divide, and present, in certain situations, as especially seen in young subjects, small *retia mirabilia* or *lymphatic networks*, inclosed in a thin areolar investment. They, moreover, pass through the bodies known as *lymphatic glands*, which may be regarded as more highly and specially developed retia (p. 60). Ultimately, the lymphatics of the lower limbs, of the lower half of the trunk, of the left side of the head and neck, and of the left upper limb, join the great trunk of the lymphatic system, the *thoracic duct*, *a*. Those from the right side of the head and neck, and right upper limb, unite to form a small separate trunk, named the *right lymphatic duct*. This enters the venous system at the point of junction of the right jugular and subclavian veins, its orifice being guarded by a double valve. A few separate and smaller lymphatic trunks are also said to enter the veins of the neck at different points. All the organs of the thoracic and abdominal cavities, have superficial as well as deep lymphatics belonging to them, Figs. 100, 101. The lymphatics were first described by Fallopius (1561), but afterwards much more fully, by Rudbeck and Bartholin; the thoracic duct was detected by Eustachius (obiit. 1570).

Fig. 101.

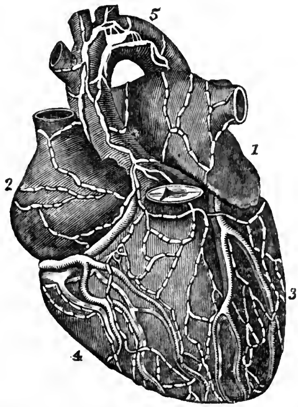


Fig. 101. Superficial lymphatics upon the heart, situated beneath the serous coat or visceral part of the pericardium. The figure also serves to show the shape, position, and subdivisions of the heart. 1, the left, 2, the right auricle; 3, the left, 4, the right ventricle; 5, the descending part of the arch of the aorta.

The thoracic duct (Fig. 100 *a*), begins below by a dilatation, named the *receptaculum chyli*, usually placed upon the second lumbar vertebra. From this point, the duct ascends, somewhat tortuously, in front of the vertebral column, into, and through, the thorax. Placed, at first, a little to the right of the aorta, it passes, opposite the third dorsal vertebra, behind the arch of that vessel, crosses over the œsophagus, and ascends on its left side to the root of the neck, *c*, where it curves downwards and outwards, behind the great bloodvessels, and finally opens into the angle of junction of the left internal jugular and subclavian veins, the entrance being guarded by a strong double valve. The thoracic duct measures from eighteen to twenty inches in length, and from two to three lines in width; it is somewhat varicose, or constricted at intervals, owing to the presence within it of numerous double semilunar valves, which have their free margins directed upwards, so that they are closed by downward pressure, and support the weight of the column of fluid contained in the duct. At the root of the neck, the contents of the absorbent system are poured into the venous system, and are mixed with the venous blood flowing towards the heart, regurgitation from the veins to the absorbent trunks being prevented by the valves placed at the opening of the latter into the veins.

The coats of the lymphatics, as elsewhere explained, are remarkably thin, and therefore highly permeable to fluids. The trunks themselves are very difficult to find, and even the thoracic duct eludes an ordinary dissection.

Lymphatic *glands* are found (Fig. 100) in the arm-pits and groins, and a few at the bend of the elbow, and in the ham, where they are named respectively *axillary*, *inguinal*, *anti-brachial*, and *popliteal* glands; chains of glands on each side of the neck, are named the *cervical* or *concatenated* glands; in the thorax, numerous glands, placed around the great air-tubes or bronchi, and usually containing a black deposit, are named *bronchial* glands; lastly, in the pelvis and abdomen, are the *iliac*, *lumbar*, and *mesenteric* glands.

Like general absorption, the absorption of food from the alimentary canal is performed by the agency not only of the *bloodvessels* but also of the *absorbents* proper; those of the small intestines, which occasionally—that is, during digestion—convey the milky white fluid, *chyle*, are named the *lacteals*, or *chyliferous* vessels.

The *arteries* of the intestine, chiefly derived from the mesenteric arteries, subdivide and inosculate in the mesentery, forming numerous vascular arches before they reach the attached border of the intestine; entering and ramifying in the submucous coat, their branches penetrate, and further subdivide in the mucous membrane, in which they end in close networks of *capillaries*, near the mucous surface, around the intestinal tubuli and glands, and within the countless villi. From the capillary networks, the minutest *venules* proceed, and soon join to form larger veins, running to the attached border of the intestine; beyond this, the veins unite in the mesentery into still larger trunks; these, with the veins of the stomach, pancreas, and spleen, ultimately form the portal vein, which enters, and subdivides in the liver. The veins from the lower part of the large intestine, however, do not enter this portal system, but join the veins from the lower half of the body; so, too, the veins proceeding from the mouth, pharynx, and gullet, enter the general venous system.

The *lacteals*, which may be said to be limited to the small intestine, below the entrance of the bile-duct and pancreatic duct, resemble the lymphatics of the stomach, large intestine, and other parts of the body, and, like them, convey, when not engaged in absorbing food, only a transparent lymph. The lacteals were discovered by Aselli (1622); their connection with the thoracic duct was shown by Pecquet (1651). In the mucous membrane of the stomach and large intestine, the absorbents probably arise by networks, like those of other membranes. In the small intestine, however, which is the proper seat of lacteal absorption, besides a network near the general mucous surface, absorbent vessels, which form, as it were, the *radicles* or absorbent extremities of the lacteal system, commence within the villi which specially characterize this part of the intestinal canal. These villi, during digestion, project into the pulpy digested food, as the rootlets of a plant, with their absorbing spongioles, depend in water or penetrate the soil.

The lacteals commence within the villi by closed extremities, and not by open mouths (Fig. 102, 1). By some anatomists they are said to arise by a plexiform network, which, at the base of the villus, passes into larger vessels. According to others, a single lacteal vessel occu-

Fig. 102.

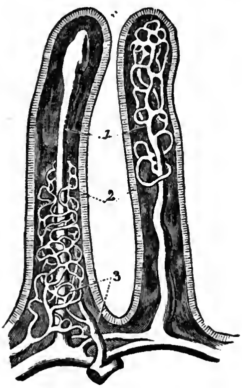


Fig. 103.

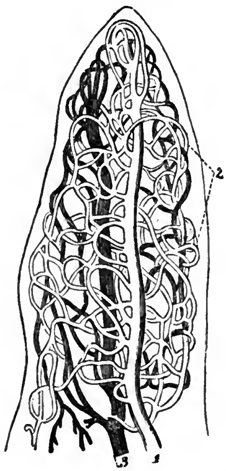


Fig. 102. Two intestinal villi highly magnified, showing the two supposed modes of commencement of the lacteals, 1. in their interior; one mode, by a dilated ampulla, the other by a network. The columnar epithelial cells. 2, covering the villi, are also shown; and likewise a portion of the capillary network, 3, lying outside the lacteal vessel. The larger lacteals at the base of the villi are indicated.

Fig. 103. The artery, capillary network, and vein of an intestinal villus artificially injected. The light-colored vessel represents the minute artery which conveys the blood into the villus; the dark vessel is the vein along which the blood returns; the intermediate capillary network is marked 2.

pies the centre of each villus, commencing near the apex by a simple closed extremity, by a dilated ampulla, or by a loop, which may be part of a network, and ending in the general network at its base. The diameter of the lacteals in the villi, is from $\frac{1}{1000}$th to $\frac{1}{800}$th of an inch.

The network at their base consists of a finer and a coarser layer, in the latter of which the vessels possess valves. (Teichmann.) The villi are also very vascular, each containing a minute arterial and venous twig, with a close capillary network outside the lacteal vessels (Fig. 102, 3, and Fig. 103). The substance of the villus consists of a delicate extension of the mucous membrane, composed of a mixed, soft areolar and granular tissue, containing fatty particles; further, each villus contains, around the central lacteal, a few unstriped muscular fibres, by the contraction of which the villus may be shortened, and its substance thrown into transverse folds; lastly, the epithelial covering of the villus, which measures only about $\frac{1}{1200}$th of an inch in thickness, is composed, like that of the intestine generally, of a single layer of columnar nucleated cells, pointed at their attached end, but wider, flattened, and more or less polygonal at their free extremity. This part of the cell has been described as being ciliated, but the appearance is generally attributed to the existence of fine lines passing from the free end to the interior of each cell, and regarded by some as pores. In animals killed while lacteal absorption is going on, these epithelial cells are frequently found to be distended with fatty matter, the villi having a swollen and tuberculated aspect. At this time also, the central lacteals of each villus, and also the subjacent vessels, are found distended with whitish or bluish chyle. Upon the surface of the small intestine (Fig. 104, 1), running beneath the peritoneal coat towards its attached border, are seen larger chyliferous vessels, proceeding between the layers of the mesentery, 2, 2; thence others, passing through the *mesenteric* glands, 3, converge to the back of the abdomen, where they end in the *receptaculum chyli*, or dilated part of the thoracic duct (Fig. 100, *a*). If this duct be tied immediately after death, in an animal killed during digestion, it, as well as the chyliferous vessels generally, becomes much distended, and either of these vessels may burst, and the chyle may be extravasated at many points.

Beneath the mucous membrane in various parts of the alimentary canal, as in certain recesses at the root of the tongue (p. 520), and in the tonsils (p. 501), or scattered singly over the internal surface of the stomach, small intestine, and large intestine, and, lastly, collected in patches in the small intestine, there exist peculiar saccular bodies, called glands, which, however, do not appear to belong to the secreting gland system, but perhaps rather to the absorbent system. They are neither racemose glands, like the glands of Brunner, nor open follicles, nor tubuli, like the gastric glands and the crypts of Lieberkühn, but *closed sacs*, not communicating with the interior of the intestine, unless under some exceptional conditions. In the stomach and intestine, these bodies exist in two forms. First, as the so-called *solitary* glands of the stomach (p. 526), small intestine (p. 544), and large intestine (p. 544), scattered over the mucous surface, as small soft whitish bodies, somewhat prominent, and about one line in diameter, or the size of a millet-seed when they are fully distended. Each sac consists of a thickish soft capsule, composed of an indistinctly formed areolar tissue, mixed with nuclei, and incloses a semi-opaque, adherent, and semifluid granular matter, containing mixed fatty and albuminous molecules, nuclei, and cells, amongst which loops of capillary vessels are said to penetrate from all sides. The mucous membrane passes completely over these sacs, and usually even a few villi are placed upon them. In the large intestine, they are situated at the bottom of a wide recess, having a narrow orifice, which has been erroneously regarded as an opening into the sac. Secondly, clusters of these sacs, the *agminated glands*, or Peyer's glands (Peyer, 1677), are found in the small intestine only. These Peyer's patches, twenty to thirty in number, are either rounded or oval, being from half an inch to three or more inches in length, and about half an inch or more in width; they are placed at intervals, longitudinally along the free border of the intestine (Fig. 91). Commencing, of small size, in the lower part of the duodenum, they gradually become more frequent and larger in the jejunum and upper part of the ileum, but are largest and most numerous in the lower part of the ileum. Their component sacs (Figs. 98, 99), exactly resemble in structure the single sacs of the so-called solitary glands. When distended, as occurs during the absorption of food, the patches of Peyer's glands present a whitish speckled appearance, and, if moderately magnified, each sac is seen to be surrounded by a little zone of darkish points, which are the mouths of the crypts of Lieberkühn, thrust outwards by the filling of the sac. The mucous membrane over the sacs, is entire. Villi are seen in the intervals between them, and sometimes, as is the case with the solitary glands, even upon them. Opposite these patches, the submucous coat of the intestine is more vascular than elsewhere, and especially abounds in lymphatics, which, however, have not been traced into the sacs, but here form plexuses of large and easily injected vessels.

Fig. 104.

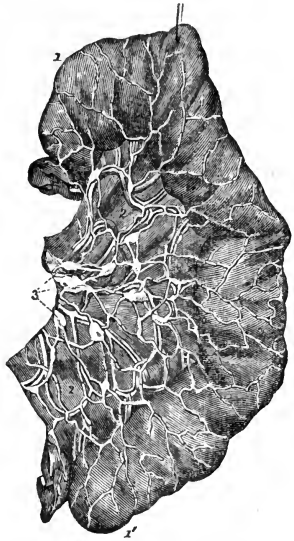


Fig. 104. Portion of the small intestine, 1, 1, with its mesentery; 2, 2, showing the superficial lacteal vessels in the intestine and mesentery. The mesenteric glands are also seen at 3 and elsewhere.

The sacs of both the solitary and the agminated glands are sometimes found open, as if by rupture through distension; but from their normally closed condition, the fatty and albuminoid nature of their contents, the abundance of lymphatics in their neighborhood, and from the special distension of these, as well as of the sacs themselves, during the process of intestinal absorption, it is with much reason inferred, that both the solitary and agminated glands are concerned, in some way, in this last-named function; the mode in which they act, and the precise nature of their office, are, however, not yet understood.

Endosmosis, Exosmosis, Osmosis, Liquid Diffusion, and Dialysis.

The absorption of liquids, or of substances in a state of solution, by the living animal body, is either a simple filtrating process, connected with the fine *porosity* of the tissues; or it partakes of the character of *dialysis*, or the penetration of liquid or dissolved substances through a moist membrane permeable to such bodies, without being directly porous, like a filter; or, lastly, it may be connected with special *selective* or *repellent* actions in the living tissues. Even in the last case, the process may be physical, *i. e.*, either filtrating or dialytic. The penetration of dissolved substances through the tissues, occurs, not only in general absorption and the absorption of food, but also in intrinsic absorption, in all acts of nutrition, in the reabsorption of the disintegrated materials of the body itself, likewise in the various acts of secretion and excretion, in certain processes of the function of respiration, and of those of taste and smell.

Endosmosis.—The action of the living tissues, in these several functions, has, since the researches of Dutrochet (1827), been in part referred to the physical processes of so-called *endosmosis* and *exosmosis*, or the passage of fluids in opposite directions through dead animal membranes (ἔνδον, *endon*, within; ὠσμός, *osmos*, impulse). It was first pointed out by Parrot, of St. Petersburg (1803), that if two liquids of unequal density are separated by a permeable organic membrane, a mutual but unequal interchange takes place between them; but Dutrochet more fully investigated the subject. His *endosmometer* consists of a bell-shaped glass, covered at its mouth with a thin animal membrane, and fitted at its upper end with a graduated tube; a colored solution of sugar, gum, or some saline substance, being introduced into the glass, the covered mouth is then immersed in water, when it is found that the solution rises in the graduated tube, to a considerable height above the level of the water around it. This phenomenon Dutrochet named *endosmose.* During its occurrence, however, some of the dissolved substance contained in the tube, passes into the water outside, and this process he named *exosmose.* The more rapid flow, however, usually takes place from the rarer to the denser fluid; and hence, if the endosmometer be filled with water, and be dipped in the solution, the more active, or so-called endosmotic current, really passes *outwards* through the membrane. Dutrochet pointed out that the force of endosmosis bears a certain ratio to the density of the inner fluid, and that the quantity of fluid which passes, depends also on the extent of the membrane. To avoid the effects of gravity, he from time to time adjusted the endosmometer, so that the fluids inside and outside, were kept on a level. He showed that capillarity, or capillary ascension, does not account for the phenomena, which, he admitted, cannot be satisfactorily explained. He supposed that endosmosis and exosmosis are peculiar to organic membranes, and that they explain the rise of the sap in plants, many processes of the animal body, and probably also the motions of various vegetable and animal fibres and cells.

More recently, these physical phenomena have been studied by Beclard, Matteucci, Graham, and others. The direction of the current through an animal membrane, is not always found to be from the lighter to the denser fluid; for water passes more rapidly into alcohol, than alcohol into water. The great endosmotic tendency of water has been attributed to its high specific heat, which is higher than that of any other fluid. (Beclard.) But the properties and qualities of the various fluid, or saline and other soluble substances, are also found to influence the result. The phenomena are favored by moderately high temperatures, by pressure, by the saturation of the membrane with acids or alkalies, by special relations between the membrane and one of the fluids, and by the constant removal of the endosmosing fluid by motion or by evaporation.

Professor Graham has examined separately, first the tendency of different liquids or solutions to mix with each other directly, and, secondly, the influence of a permeable membrane interposed between them. The former phenomena constitute *liquid diffusion*, and the latter *osmosis*, or *dialysis*.

Liquid Diffusion.—A phial, with open mouth, is filled, nearly to the top, with a given solution, and is then placed in a larger vessel, into which water is carefully poured, so as to stand considerably above the level of the mouth of the phial;

or a graduated jar is filled, up to the highest mark but one, with water, and then, by means of a pipette, the solution to be tried is poured in at the bottom of the jar, so as to elevate the water to the top of the scale. On leaving phials or jars, so prepared, standing, without agitation, or change of temperature, the substance in solution ascends in the water, against the influence of gravity, as if it were volatile. In other words, it diffuses; hence the term liquid diffusion. All soluble substances diffuse in this way, but they are not equally diffusible. Thus, in phial experiments, the relative quantities of the following substances, diffused through the water above, from solutions of like concentration, in the same time, are as follow: chloride of sodium 58, nitrate of soda 57, sulphate of soda 27, cane sugar 26, gum 13, and albumen 3. In jar experiments, the relative times of diffusion of equal quantities of different substances are these: hydrochloric acid, the most diffusible substance hitherto tried, 1; chloride of sodium 2.3; sugar 7; sulphate of magnesia 7; albumen 49; and caramel, or burnt sugar, 98. The rate of diffusion of different substances is, therefore, remarkably different, being very high for hydrochloric acid and chloride of sodium, but low for gum, albumen, and caramel. So distinct and constant is the diffusive power of different substances, that, from mixed solutions of these, chloride of potassium ascends more rapidly than common salt, and this, faster than sulphate of soda; with salt and albumen, the difference is still more marked. Weak chemical compounds may even be decomposed through the different diffusive power of their constituents; thus, alum, a double sulphate of alumina and potash, is decomposed, in a phial diffusion experiment, by some of the sulphate of potash rising away from its associated sulphate of alumina.

The rate of diffusion, in proportion to the quantity of the substance diffused, is greater when the solution is weak; but the absolute quantity diffused is greater with strong solutions. Heat increases the rate of diffusion, common salt, *e. g.*, diffusing $2\frac{1}{2}$ times more rapidly at 120° than at 60°.

From various points of contrast, including their behavior as diffusible bodies, chemical substances are arranged by Graham into *crystalloids* and *colloids*.

Crystalloid bodies are hard, rigid, and quickly soluble; their solutions are never viscous; they are always more or less sapid; their chemical reactions are quick and energetic, but in the molecular sense, they are, if left to themselves, static, or little liable to molecular changes. This class includes every crystallizable body, and every substance capable of entering into the formation of a crystalline body.

Colloid substances do not crystallize, but are amorphous; they have, when dry, a vitreous structure, and instead of being hard and brittle, are soft or tough; they dissolve freely but slowly, their solutions being more or less viscous, and they gelatinize on cooling, or by concentration. Hence they are named colloids, from collin or gelatin, and sometimes pectoids, from their gummy character; they are tasteless or insipid, but they may give rise to sapid crystalloids; their combining equivalents are high, and their molecules accordingly heavy; as acids, or bases, they are chemically inert, but they are liable to remarkable molecular changes, and, in this sense, exhibit great dynamical activity; they have a weak affinity for water, and are easily thrown down from their solution in it. They readily undergo metastasis, passing from a state of solution into the gelatinous, pectous, or solid condition, and, with time, even into the crystalloid state, either spontaneously, or by the slightest contact with extremely minute portions of other substances; thus a solution of silicic acid is gelatinized by $\frac{1}{10000}$ part of an alkaline or earthy carbonate. Lastly, in their soft condition, they form, like water, media for liquid diffusion, a crystalloid body diffusing itself through a jelly, almost as readily as through water itself. Colloid substances include gelatinized starch, dextrin, gum, caramel, gelatin, albuminoid bodies, vegetable and animal bodies, extractives, and a number of soluble hydrated mineral substances, as, for example, silicic acid and peroxide of iron.

Of the two great classes of substances thus distinguished, crystalloids are highly diffusible, whilst colloids are of low diffusibility.

Finally, liquid diffusion is to be regarded, not as a purely physical process, like the diffusion of gases, which depends on a tendency of those elastic fluids to intermix in inverse proportions to their density; nor is it to be explained by capillarity; for the diffusion of different substances does not coincide with their ascension in capillary tubes; but this process appears rather to depend on chemical action. The high diffusibility of crystalloids is explained by their powerful attraction for their solvent, the mobility or volatility of which is determined by their presence; whilst the low diffusibility of colloids is referred to their feeble combination with their solvent, on the volatility of which they accordingly have little effect.

Dialysis.—The phenomena of the diffusion of liquids into each other are rendered more definite by the interposition of permeable membranes between them. If a gutta-percha hoop be closed on one side with vegetable parchment, the tray thus formed will not allow water to pass through it by filtration. By supporting, or suspending, such a tray in a large vessel of water, and pouring a thin layer of the fluid or solution to be experimented upon, into it, *dialysis*, or diffusion through the permeable membrane, takes place. Crystalloid bodies, in solution, pass through the membrane, or dialyze, into the water, with great rapidity; whilst colloid bodies are almost absolutely prevented from passing. Thus, in equal times, the proportion of common salt which dialyzes is 7.5, of cane sugar 1.6, and of gum .029; or, again, the quantity of salt which dialyzes being 5.2, that of dextrin is .034, of gum .013, of caramel .009, and of albumen .005; whilst gelatin, extract of meat, and boiled starch, do not dialyze at all. The rate of dialysis is influenced by the depth of the fluid in the tray, by the area of the membrane, by the strength of the solution, and, to a certain degree, though less than liquid diffusion, by temperature. The process is not mechanical, but chemical, the results being more definite than those of liquid diffusion. Dialysis depends on the affinity of the substance experimented upon, for the water in the moist permeable membrane. Crystalloids, which dialyze rapidly, have an affinity for, or unite with, the water of the septum, and, by successive combinations of their molecules with the water in that membrane, they pass through to the water outside it, and thus a movement, otherwise invisible, becomes apparent. On the other hand, colloids have little or no affinity for the water of the septum, and, therefore, do not make their way through it. The membranous septum is itself colloidal; its molecules have, therefore, only a slight affinity for water, and permit the stronger affinity of the crystalloids, successively to displace them, and so to pass through; whilst colloids generally, are too feeble to accomplish this displacement. Thin layers of any colloidal substance, such as films of gelatinized starch, albumen, jelly, gum, and mucus, also act as dialyzers.

Dialysis has been employed for the artificial separation of crystalloids and colloids. Saline and earthy matters, rendered soluble by acetic or hydrochloric acids, may be dialyzed from albumen, or lime from solutions of gum, pure albumen or gummic acid remaining. Morphia, strychnia, and other crystallizable alkaloids, have been separated from organic fluids; and even $\frac{1}{10000}$ part of arsenious acid, mixed with porter, milk, defibrinated blood, or pieces of intestine, has yielded 80 or 90 per cent. of that minute quantity, by dialysis, in 24 hours. These dialytic actions also explain more completely, the long known phenomena of endosmosis and exosmosis. The force concerned in liquid diffusion was at first named, by Graham, *osmotic* force; and endosmosis and exosmosis were regarded, by him, as due to the action of this force in opposite directions, or to a positive and negative osmosis; the direction of the chief visible current appears to be always towards any substance having the properties of a base, water flowing towards a salt, and from an acid. Subsequently, however, Graham distinguished liquid diffusion from diffusion through membranes, or dialysis.

Dialysis must take place in the living body, in which compound and simple permeable and colloidal membranes abound, such as the basement-membranes, capillary walls, and cell walls, all of which are subject to the constant action of solutions of crystalloid and colloid bodies, either acids, alkalies, and salts, or albuminoid and extractive substances. The process of absorption most obviously suggests diffusive and dialytic actions; but so also do those of nutrition, secretion, and excretion, and even the interchange of the gases of the blood and air, in respiration, for these gases are dissolved at the moment of interchange. Moreover, the sapidity of crystalloids and the insipidity of colloids are associated respectively, with a high and a low diffusibility. It has even been suggested, as indeed was hinted by Dutrochet, that rapid dialytic action may take place, not only in vegetable movements, but also in the intimate changes of condition of the muscular fibres, in the states of contraction and relaxation, and that it may thus form a link in the transformation of chemical into mechanical force, which is realized in animal motion. Lastly, organization and living action are indissolubly associated with the existence of one at least of these two great classes of substances, discriminated by their different dialytic power; for all the tissues of plants, and animals, from those of the seed or germ, upwards, are colloidal in their nature.

[This interchange will ordinarily continue until the specific gravity of the two fluids is equal.

In the instance given in the text, the more rapid current will be from the rarer to the denser medium, and the less rapid from the denser to the rarer; and although this is the law in the majority of instances, there are many exceptions. Thus, if alcohol, or ether, be placed in the osmometer, and water in the exterior vessel, the latter will pass through the membrane with greater rapidity to the former. Again, a saturated solution of oxalic acid, sp. gr. 1.045, at 77° F., placed on one side of an animal membrane with water on the other, will pass to the latter, augmenting its bulk, and diminishing its own specific gravity. Solutions of citric and tartaric acid at a sp. gr. below 1.05 pass to the water, while at a sp. gr. above 1.05 the water passes to the acid solution. Whence, it is plain that density, *per se*, is not the cause of increase of bulk in osmotic movement.

This interchange of fluids, separated by an animal membrane, will be found to take place in all instances where the two fluids are not of equal specific gravity, and not chemically incompatible or non-miscible; though in such varying degree, that while on the one hand an instantaneous response may be noted in the case of many fluids, as solutions of common salt, and the potash salts, others, as oil and albumen, can scarcely be said to be capable of osmosis in their natural state and under ordinary circumstances. Many of these substances, however, which do not osmose under ordinary circumstances, may be caused to do so by *pressure*, which is one of the potent modifiers of the process. Though the effect of equal degrees of pressure varies with the thickness of the membrane, it has been found by Liebig, that to force the fluids below named through ox-bladder $\frac{1}{10}$th of a line in thickness,—

Water requires a pressure of but	12	inches of	mercury,
Saturated solution of salt, "	18	"	"
While marrow oil requires, "	34	"	"

When the membrane used was the peritoneum of a calf $\frac{1}{20}$th of a line in thickness,—

Water required a	pressure of	8.10	inches of	mercury,
Solution of salt,	" "	12.16	"	"
Marrow oil,	" "	22.24	"	"
Alcohol,	" "	36.40	"	"

According to which the "amount of pressure required is inversely as the force of capillary attraction; that is, where the greatest capillary attraction exists, there less pressure is required."*

It has been the object of numerous researches by Dutrochet, Matteucci, Liebig, Vogel, Prof. Graham, and others, to ascertain the physical causes and vital influences determining this process; and as the result of their labors, it has been pretty well determined that osmosis depends, in the first place, upon *two essential conditions*, but is further influenced by several causes.

The *first essential condition* of osmosis is a greater affinity of one fluid for the membrane over that of the second fluid for the same membrane,—that is, one fluid must have a greater power of wetting the membrane than is possessed by the other fluid. If such does not exist, no current will be developed. It is plain that this *imbibition*, or wetting of the membrane by the fluids, is nothing else than an effect of *capillarity*, the property possessed in various degrees by fluids, of ascending very fine hair-like tubes, here provided by the meshes of the membrane. That different fluids possess a different power in this respect was shown by Liebig, who found that 100 parts of ox-bladder took up in 24 hours—

Of pure water, ...	268 vols.
" saturated solution of sea salt, . .	133 "
" alcohol of 84 per cent., . . .	38 "
" oil of marrow, ...	17 "

That such different affinity exists not only on the part of different fluids for the same membrane, but also of the same fluid for different membranes, may be shown by the following experiment: Let three open tubes be covered at one extremity with a piece of pig's bladder, and filled with water, alcohol, and ether, respectively; three others covered similarly by india-rubber, filled with the same fluids, and all be inverted in a basin of mercury. After an interval of a few hours, it will be found that the mercury has risen in the tube covered with bladder and containing water, to a very appreciable height, while in the tube containing ether it has risen but slightly, and in that containing alcohol scarcely at all. The water, having a great affinity for the membrane, wets it rapidly, and is evaporated from its outer surface, while the mercury rises in the interior to take its place. The alcohol and ether, having but little affinity for the membrane, are not rapidly removed. In the tubes covered with india-rubber, the reverse will be found to have taken place. Here the alcohol having a great affinity for the membrane, wets it, and is evaporated from the outer surface, causing the mercury to rise in its place. This will explain the phenomena so familiar to those who are conversant with the preservation of anatomical preparations in alcohol. When the jars in which specimens are immersed are covered with bladder, the water evaporates and the alcohol becomes stronger; while if the jar be covered with india-rubber, the alcohol evaporates and that which remains becomes diluted.

It thus appears that the portion of the process of osmosis which

* Carson—Osmosis: its Agency in Action of Medicines, &c. A Review, Am. Jour. Med. Sci., July, 1865, p. 139.

includes the *direction* of the current, is due to *imbibition*, dependent upon capillarity, or capillary attraction. It is plain, however, that to cause the fluid to pass beyond the membrane, some other force must be called into play; and this involves the *second essential condition* of osmosis, to wit, *diffusion*. For "liquids flow out of capillary tubes which are filled with them, *only when some other force or cause acts*, because capillary attraction cannot produce motion beyond the limits of the solid body which determines the capillary action."*

The property of *diffusion*, common to liquids and gases, has been carefully studied by Prof. Graham, and is well illustrated by what he terms "jar or phial diffusion," detailed in the text.

While it is true that colloids are of low diffusibility in their natural condition, they may, however, be caused to undergo certain chemical or physical changes, in consequence of which they become capable of osmosis, and thus become practically crystalloids. Thus albumen, which does not ordinarily osmose, when converted into albuminose by the gastric or intestinal juices, becomes capable of absorption and is taken into the bloodvessels. So oil, when converted into an emulsion by the pancreatic fluid, becomes also capable of absorption and enters the lacteals.

Crystalloids not only diffuse among themselves, but they will gradually diffuse themselves through colloids. A simple experiment showing this fact may be thus performed: In the centre of a mass of any colloid substance, as boiled starch, let there be placed any highly colored crystalloid, as bichromate of potash; in a short time, it will diffuse itself throughout the entire mass, giving it a bright-yellow color. If, on the other hand, a colloid, as burnt sugar, or caramel, be placed in the centre of a similar mass, at the end of many days it will be found to have diffused itself scarcely at all.

In consequence of this property, when crystalloids and colloids are mingled, as in the egg, the former may be caused to diffuse themselves away from the latter.

This is beautifully shown by a simple arrangement, known as the egg-endosmometer, prepared by removing the shell from one end of an egg in such manner as to leave the membrane intact. In the opposite end, a small opening is made, around which is cemented a glass tube. The egg is then placed in a wine-glass of water, with the end upon which the membrane is intact downward. In a short time, the contents of the egg will begin to appear in the tube, showing that water has passed through the animal membrane and caused the displacement of the egg's contents. It will be found, also, that the salts or crystalloids of the egg have osmosed through the membrane, at the lower end, by adding a solution of nitrate of silver to the water in the wine-glass, when an abundant precipitate of the chlorides will take place. All the tests for albumen may, however, be applied to this water without any response,—none of the colloids, or albumen, have passed through the

* Liebig, Researches on the Chemistry of Food and the Motion of the Juices in the Animal Body.

animal membrane. It is this diffusion of crystalloids away from colloids through a membrane which is termed, by Prof. Graham, *dialysis.* It is through this second essential condition, *diffusion*, that the current is completed. When the fluid having the greater affinity for the membrane has passed through its pores and arrived at the opposite side, if it meets there with a fluid with which it is chemically compatible and into which it is capable of diffusing itself, it will so diffuse itself from the membrane, where it is replaced by a fresh supply. Thus, a constant current will be established from one side of the membrane to the other, producing the so-called *first current*, which, it will be seen, depends upon *affinity* and *diffusibility*, and whose direction is thus determined without regard to the density of either, while the rapidity of the current evidently depends upon diffusibility.

It has been stated, however, in the definition of osmosis, that there is an *interchange* or mutual action between the two liquids, that is, that a *second* or *reverse current* is produced in an opposite direction to the first. With this, affinity, at least for the membrane, has nothing to do, because the affinity of the first fluid being greatest has superseded any which the second might have. Two explanations are usually given to account for it. In the first, the reverse current is explained by the supposition that a diffusion of the second fluid takes place through the first already occupying the capillary pores of the membrane. According to the second explanation, suggested by Prof. Graham, it is not true capillary attraction which causes the flow of liquids through animal membranes, but it is due to a combination and decomposition taking place in the membrane. When a colloidal membrane is in contact with pure water on one side, and a saline solution on the other, it combines with the water, but the saline solution having a stronger attraction for the water than the membrane has, takes it away, and thus by a constant hydration and de-hydration of the intervening colloid, the motion of the currents is established (*Youman's New Chemistry*). It may, perhaps, be more clearly indicated as follows: Suppose the membrane to be indicated by *m*, the first fluid by *a*, and the second by *b*, then, although *a* has a greater affinity for *m* than has *b*, yet *a* may have a greater affinity for *b* than for *m*. Hence, *b* is taken up by *a* and carried to the opposite side. Practically, there appears little difference in these two modes of explanation, while the simplicity of the first recommends itself.

Although these two may be said to be the essential conditions of osmosis, there are certain other influences which may modify it in varying degrees.

1. To secure the most favorable condition of osmosis, a certain degree of *temperature* is necessary. If the temperature be depressed to the freezing-point, the current is almost entirely stopped; if it be much above 100°, the process is also interfered with, while a temperature of from 90° to 100° seems to be most favorable.

2. A certain amount of *motion* of the fluids is also necessary to rapid osmosis. If there be no such motion, those portions of the fluid in immediate contact with the membrane soon become of equal density on either side (unless diffusion is very rapid so as to produce

a current of itself), and osmosis will cease. If these portions be moved away, however, before or as soon as the equal density is attained, and their place supplied by fresh portions, the current will be continued.

3. *Decomposition* of the animal membrane produces a cessation of the current.

4. Certain substances of animal and vegetable origin are said to interfere with osmosis, as morphia, the woorara poison, the rabies of dogs, the poison of small-pox. The last three substances have been taken into the stomach without harm, while morphia is said to prevent osmosis of the fluids of the blood when introduced into the circulation.

5. It has already been stated that *pressure* exerts an important influence upon osmosis. It is under the influence of pressure that albumen, which does not ordinarily osmose, is caused to pass through animal membrane in certain pathological states, as where albumen passes through the bloodvessels into the uriniferous tubules of the kidney and appears in the urine.

Little further need be said of osmosis in connection with the functions of the body in which it plays a part, save for purposes of illustration. In the operation of absorption, it is of course very largely concerned; a glass of water taken into the stomach rapidly disappears, being absorbed by the endosmotic agency of the bloodvessels. Here is plainly seen the primary importance of change of place or motion on the part of at least one of the fluids separated by the membrane. Were this not the case, an equilibrium would soon be obtained and the current be discontinued; but the rapidity of the circulation in the capillaries carries away the water absorbed, and leaves room for the absorption of more.

On the same principle, fulness of the capillaries retards osmosis; whence an important practical deduction follows with regard to the treatment of poisoned wounds. If by any means at our disposal we can bring about a congestion of the bloodvessels surrounding the wound, the tendency to absorption of the poison will be greatly diminished. And this is the principle upon which the application of a cupping-glass to the wound, as revived by Sir D. Barry, or a ligature placed between the wound and the central organ of circulation, or even suction applied to the wound itself, will sometimes prevent the action of the poison.

The experiments of Christison and Magendie are illustrations of these facts. The former, after tying a ligature about the limb of a dog, introduced some poisonous material into the connective tissue beyond the ligature. So long as the ligature was allowed to remain, very little absorption took place; but immediately on the removal of the ligature and the renewal of circulation, the animal succumbed.* Magendie injected a colored liquid into the cavity of the peritoneum of an animal, having first also produced a plethoric condition of the bloodvessels by injecting them with water. So long as the plethoric

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* Christison on Poisons, p. 39.

condition remained, the colored fluid was not absorbed from the peritoneal cavity; but immediately on opening a bloodvessel, the colored fluid disappeared rapidly by absorption. An important therapeutic application is seen in the treatment of dropsies, or at least those involving the great serous cavities, where the absorption of the effused serum is accelerated by drawing away a portion of the fluid constituents of the blood, by the aid of diuretics and cathartics.

An excellent *résumé* of this entire subject will be found in the *American Journal of the Medical Sciences for July*, 1865, in a review entitled "Osmosis: its Agency in the Action of Medicine," by Prof. Joseph Carson, which has been freely used in the preparation of this note. F. G. S.]

General Absorption.

The chief natural absorbing surface is the mucous membrane of the alimentary canal. Thus, it takes up the greater part of the food; moreover, saline, coloring, odorous, sapid, and other substances, may be detected, soon after having been swallowed, not merely in the blood, but in the secretions of distant glands; and, lastly, specific effects, medicinal or poisonous, may be produced upon remote parts of the system, *e. g.*, upon the brain and spinal cord, as when prussic acid is applied to the tongue, strychnine is taken by the stomach, or nicotine is administered in enemas.

The mucous membrane lining the air-passages and air-cells of the lungs, is also absorbent, that of the air-cells especially taking up gases in a state of solution. Water, various other fluids, and saline solutions, accidentally introduced into the air-passages, are also partly absorbed. From certain cases of increase in the weight of the body, beyond that of the food and beverage taken, it has been inferred, though this is doubtful, that the pulmonary mucous membrane may even absorb the vapor of water from the air, instead of exhaling it, as it usually does. Many substances, of a more or less volatile or soluble character, may be introduced into the system through the air we breathe, either in a vaporous state, as in the case of carburetted, sulphuretted, phosphuretted, and arseniuretted hydrogen, cyanogen, alcohol, ether, chloroform, mercury, phosphorus, and miasmatic and contagious exhalations, or in the condition of fine particles, as *e. g.*, arsenic. The general anæsthesia produced by chloroform, depends on its absorption by the pulmonary capillaries. Mercury and phosphorus, employed by the looking-glass manufacturers, and lucifer-match makers, are taken up, partly by the mouth, but also probably by the lungs; and numerous cases of poisoning by arsenic, in which the health has been seriously deranged, have been observed amongst manufacturers of artificial flowers and green paper hangings, from the arsenite of copper, or Scheele's green, employed by them. Such papers are unfit for dwelling-rooms.

The conjunctiva is also absorbent, as is shown by the poisonous effects of prussic acid dropped into the eye of a rabbit. Other mucous membranes likewise absorb fluids and dissolved substances; the bile, for example, becomes more or less inspissated in the gall-bladder.

Absorption by the skin also takes place, especially when a substance is kept in prolonged contact with it, as in the case of painters who do not cleanse their hands from white lead, and are attacked with the dropped wrist or paralysis of the extensor muscles of the forearm. In the thin- and moist-skinned Amphibia, absorption by the integument is very active; for if kept in a condition of drought, these animals become extremely attenuated; whilst they rapidly swell out, if then placed in a moist atmosphere, or upon damp earth, thus proving that their skin is both absorbent and exhalant. A dog placed in an air-tight vessel, with its head uninclosed, has been killed by the vapor of the oil of bitter almonds absorbed only through the skin. In regard to Man, absorption through the skin, if this be whole, is not very active; indeed, it has been, though erroneously, denied. The non-vascular cuticle impedes this process, and, in this way, is of great importance, especially in the practice of certain arts, in which the body is subject to contact with deleterious agents. Nevertheless, water may be absorbed by the whole skin, for the weight of the body is increased after the use of warm baths. (Madden.) Shipwrecked sailors, destitute of fresh water, find that, by immersion in the sea, or by wetting the clothes in sea-water, thirst is relieved; this may be partly attributable to a diminution of the exhalation of water from the blood through the skin, owing to the prevention of evaporation, but it is doubtless partly also due to direct absorption. In the use of very hot baths, above the temperature of the blood, more water is lost, by perspiration and pulmonary exhalation, than is absorbed, so that the body is lighter after such a bath; in a bath of 90°, the processes of absorption and exhalation are balanced, no change taking place in the body-weight; in tepid and cold baths, cutaneous absorption exceeds exhalation, and the body gains in weight. Saline substances, such as iodide of potassium, cyanide of potassium, nitrate of potash, or chloride of ammonium, dissolved in baths, do not, according to some, enter the system; but others allege that they may be found in the blood and urine. The use of medicinal baths is based on the supposition that they are so absorbed; and the discrepancies between the results of different experiments, may, in part, depend on the employment of baths at different temperatures, which, as just stated, produce different results. A condition of exhaustion favors cutaneous absorption. The softening of the cuticle greatly facilitates the process: thus, an onion crushed and worn in the shoe, will cause the breath to smell; garlic poultices applied to the arm, and lint dipped in turpentine, to the body, produce characteristic odors in the urine; jalap poultices may have an aperient effect; whilst applications of belladonna to the skin have been followed by dryness of the throat, dimness of sight, and by alarming, sometimes fatal, symptoms of poisoning. The introduction of foreign substances through the skin is greatly aided by the thinness of the cuticle and by friction, as is illustrated by the effects on the system of mercurial inunction, and also by the rubbing in and consequent absorption of cod-liver oil; but both these substances are absorbable even without friction.

The importance of the non-vascular cuticle as a protective covering, antagonistic to absorption, is shown indirectly by the effects of its removal; thus, the surface of the true skin, exposed in blisters, absorbs with great facility and rapidity; the unprotected and highly vascular surface of the cutis is no longer able to resist the entrance of the most deleterious substances; and even the cantharidin, or active principle of the Spanish fly, used for producing the blister, is itself, sometimes, in this way absorbed. It has been stated that the lymphatics of the skin, which are very numerous and large, and have very thin walls, absorb adventitious substances, perhaps, more readily than the bloodvessels; the reverse, however, is the case with the lacteals.

The *serous* and *synovial* membranes also absorb, sometimes even very rapidly. Poisons injected into the pleural and peritoneal cavities, in living animals, are found to be most quickly taken up. Moreover, the serous exudations which occur in inflammation of these membranes, into the pericardial, pleural, and peritoneal cavities, are more or less rapidly removed by the curative process of *resorption;* the fluids poured out into the joints, in cases of rheumatic or other inflammation, and even blood extravasated into those cavities, are also, though more slowly, absorbed. The rapid absorption of the cerebro-spinal fluid (p. 236) affords another instance of the facility of absorption from an internal cavity; so likewise does the absorption of blood and other effused matters, and even that of the broken and non-dissolved cataractous lens from the interior of the eyeball.

Absorption from the areolar connective tissue is proved by the taking up, from its interspaces, of dropsical fluids, or effused blood; also by the poisonous effects of agents introduced experimentally into the areolar tissue in animals; and lastly, by the effects of the hypodermic or subcutaneous injection of solutions of morphia, or other medicinal agents, into the living human body, for the relief of neuralgic pain, and of the suffering after severe operations, or for the purpose of inducing sleep, or of relieving obstinate cough or other irritation.

Lastly, absorption from the artificial surfaces of *ulcers* and *wounds*, is shown by the taking up of medicinal or poisonous substances, such as mercury, arsenic, morphia, atropine, conium, and other substances, applied to granulating sores.

The *vessels* concerned in general absorption in the vascular tissues, are the bloodvessels and lymphatics; but in the non-vascular tissues, as well as in non-vascular animals, absorption must take place by direct permeation into the cells or other tissue elements.

Absorption by the veins, or *venous absorption*, is proved by cutting across the limb of an animal, excepting its chief artery and vein, and then applying strychnine below the place of section, when the poison will still act, being conveyed in the blood of the undivided vein. Poisoning still takes place, if the artery and vein be also divided, and then rejoined by pieces of quill, so that the poison cannot be imbibed and conveyed by the coats of the vessels, but can only pass along the venous blood current. To show that the poisoning does not take place through the nerves, all parts of a limb may be divided, excepting the chief nerve, when poison, applied to it, does not affect the animal. Absorption by the veins generally, has also been proved by blistering the skin, applying a solution of ferro-cyanide of potassium, and, after a time, examining the blood in the veins, when that salt has been detected in it. Absorption also occurs through the portal veins. The pulmonary veins likewise absorb; for prussiate of potash, in solution, introduced into the trachea, appears sooner in the left cavities of the heart, to which the blood returns from the lungs, than in the right cavities, to which the blood returns from the body generally. Absorption by the pulmonary vessels also takes place in the passage of dissolved oxygen into the blood during respiration.

In absorption by the bloodvessels, the dissolved substance passes through the thin walls of the capillaries, or finest venules, and so enters the circulation; but as these vessels are always covered by tissue, sometimes exceedingly thin, as in the air-cells, and sometimes thicker, as in the cutis, the absorbed substances not only pass through the coats of the vessels, but must also permeate this overlying tissue. This part of the absorptive process, corresponds with that form of absorption which occurs in the non-vascular tissues and in animals destitute of vessels. Absorption never takes place through the open mouths of vessels, as was formerly supposed; but, instead, a process of permeation occurs through the living tissues, physically identical with that of dialysis through dead animal and other moist permeable membranes, out of the body. This permeation is determined generally, first, by the tendency of different solutions to mix together, or of certain substances contained in the fluid on one side of the membrane, to pass into the fluid on the other side, which does not contain them; and, secondly, by certain chemical relations between the membrane and the substances applied to it, so that the membrane will permit some things to pass through it more readily than others. The rapid dialysis of acids, salt, sugar, and other substances, as proved by their quick production of flavor in the mouth, and the equally rapid passage of saline and metallic poisons, especially of the vegetable alkaloids, cyanide of potassium, prussic acid, and many other foreign and noxious substances, into the blood, corresponds with their crystalloid character; whilst the inert colloidal gum, and albumen, are slowly absorbed and are almost tasteless. The removal of the dialyzed material, from beyond the septum, increases the rapidity of the process; and thus also, the natural process of absorption is more rapid, the quicker the circulation in a part; for the constant renewal of the blood keeps up the required difference between that fluid and the solution of the foreign material, and the quicker the circulation the more rapid and complete is the renewal of the blood.

Absorption by the bloodvessels is necessarily favored by the thinness of the layer of tissue which covers them, and is opposed by a thicker and denser covering; thus, absorption is very rapid from the lungs and peritoneum, quick also from the gastric and intestinal mucous membrane, not quite so quick from the exposed surface of the cutis, whilst it is almost entirely arrested when this is covered by the cuticle. It is very rapid from the subcutaneous cellular tissue, where solutions injected artificially come into almost immediate contact with the walls of the capillaries and venules. Absorption takes place, though slowly, through the coats of even the larger veins, as has been shown, by exposing and insulating such a vein in an animal, and placing poison upon it, when death has followed. Absorption is favored by moderate temperatures, but is retarded by temperatures much higher, or much lower, than that of the blood.

The rate of absorption of certain substances is very rapid; ferrocyanide of potassium introduced into the stomach, has been found in the urinary excretion after the short space of 60 seconds; but when the stomach is more or less full the absorption is retarded accordingly. (Erichsen.) The rapid passage of saline substances into the saliva has been shown by Bernard. Alcohol is absorbed so quickly, that its effects on the brain, when injected into the stomach of dogs, are almost immediate, death occurring in about two minutes, the stomach being then found to be empty, and the blood to contain large quantities of alcohol. (Percy.)

Substances once introduced into the veins, by absorption, are carried with the blood to the heart, and thence along the arteries to every part of the body. The condition of the circulation materially affects the rapidity of absorption. If the vessels be full of blood, or even if they be artificially injected with water, it is found that water introduced into the pleura is absorbed more slowly (Magendie); if the vessels be emptied by previous venesection, absorption takes place more rapidly. Absorption is also more active, when the water of the body has been diminished by abstinence from fluids, or by unusual excretion. It is often suggested, that persons about to expose themselves to contagion or malaria, should previously take food, so as to diminish the chances of absorption, which is believed to be more likely to occur when the bloodvessels are in a comparatively empty state, or when the system is imperfectly nourished. The supposed immunity may be due to the less exhausted condition of the nervous system, or to some other unrecognized power of resisting diseased influences.

The process of absorption by the bloodvessels is so dependent upon the movement of the blood, that if a ligature be placed on those vessels in the limb of an animal, or entirely around the limb, either, in the former case, absorption takes place slowly through the lymphatic vessels only, or, in the latter case, it does not occur at all. Thus, if a poison be inserted under the skin of an animal's foot and a tight bandage be applied round the limb, no symptoms of general poisoning ensue; but if the bandage be then removed, and the circulation through the limb be restored by gentle friction, poisoning, or even death will occur. Hence, the immediate ligature of a limb *above* a wound inflicted by a poisonous serpent, will arrest the further entrance of the venom into the circulation. The application of cupping-glasses to a poisoned wound, operates, not merely by drawing out portions of the poison, owing to the removal of atmospheric pressure from the part, but, also, by stagnating the circulation in the injured and adjacent parts; sucking a poisoned wound acts in a similar manner. In a certain degree, the destruction of the part by caustic, or the actual cautery, also operates thus, but also by the simultaneous destruction of the poison itself. The prompt removal of the poisoned tissues also arrests further absorption.

The process of absorption is influenced by the nervous system, for, after division of the sciatic nerve in the hind limb of a guinea-pig, aconite, which was not previously taken up through the skin, has been found to be absorbed; this has been attributed to the dilatation of the smaller arteries, which follows section of the vasi-motor nerves. (Waller.) Certain stimulating agents, such as chloroform and turpentine, which favor absorption, may do so, by producing dilatation of the bloodvessels, as is indicated by the increased redness of the surface to which they are applied. It has been supposed that galvanism promotes absorption, but the contrary seems to be the case. Heat, friction, and moisture, as well as exercise of a part, obviously favor absorption; whilst the opposite conditions of cold, rest, and absolute dryness, disqualify a part from performing this function.

The share of the process of general absorption due to the absorbent vessels, *i. e.*, to *lymphatic absorption*, is small. When the cuticle of an animal is removed by blistering, and a solution of ferro-cyanide of potassium is applied to the denuded cutis, though the poison may be found in the veins, it has not been detected in the thoracic duct. Nevertheless, even when the abdominal aorta and inferior vena cava of an animal have been tied, to prevent the circulation of the blood through the hinder limbs, and when, in addition to this, the internal iliac veins have also been tied, to cut off the collateral circulation through the veins of the pelvis, cyanide of potassium, and strychnine, inserted beneath the skin of the feet, even after the limbs have become rigid, have been detected above the seat of the ligatures, and have produced characteristic symptoms of poisoning; the lymphatic vessels must here have been the channels of absorption. In certain instances, morbid products are conveyed through lymphatic vessels, as, *e. g.*, decomposed animal fluids, pus, simple or specific, and also cancerous matter; but the extension of disease along the course of the lymphatics, and through the lymphatic glands, may be sometimes due to the propagation of a morbid process in the coats of the lymphatics. The coloring matter of the bile has been seen in the lymphatics of the gall-bladder, after ligature of the gall-duct, and consequent retention of the bile in its receptacle. The subcutaneous lymphatics near tattooed portions of the skin, are sometimes found charged with coloring matter, forming characteristic ramified lines, differing in course from that of the bloodvessels. Moreover, the identity of structure between the lymphatics and the lacteals, and the undoubted absorbent function of the latter, favor the conclusion that the former vessels likewise absorb. The termination of all the lymphatics in the venous system, and the direction of the valves in their interior, not only support this view, but enable us to determine the course and destination of their contents.

The *lymph*, elsewhere described (p. 61), resembles chyle deprived of its molecular basis, and of nearly all its fatty matter; but its clear, colorless, and limpid character, so unlike the milky opalescent aspect of the chyle, renders it difficult of detection in its vessels during life. Distended transparent lymphatics have, however, been seen on the surface of the liver in recently killed animals, and the lymph itself has been observed flowing from the cut surface of that organ, and also from lymphatic fistulæ, the result of disease in man, and from artificial openings established in the lymphatics of a horse's leg.

The constituents of the chyle are derived essentially from the digested food, but the precise source of the lymph contained in the lymphatics, and also in the lacteals, during the intervals between digestion, is not perfectly understood. In part, the lymph would seem, from its similarity in composition, to be derived from the nutritive plasma, which permeates all the living tissues. This plasma, itself derived from the liquor sanguinis, consists chiefly of that part of the nutrient fluid poured out through the walls of the capillaries, which is not employed for the nutrition of the tissues. The surplus of nutrient materials, together with sufficient water, is supposed to pass into the lymphatics in the form of lymph, and so to be ultimately returned to the blood. It is also supposed that the tissues, themselves undergoing nutrient changes, yield products which may, in part, be fitted to enter the commencing lymphatics; but these, no doubt, chiefly find their way into the capillaries and minute venules, and thus entering the blood, are subsequently cast off as excretory products. Whatever be its source, the fluid and dissolved constituents of the lymph find their way into the commencing lymphatics, through the delicate coats of these vessels, which form closed tubes, having no open mouths, and no direct communication with the capillary or other bloodvessels. It has, however, been recently maintained, that the commencing lymphatics communicate with, or originate in, lacunar spaces, situated in the areolar tissue which pervades the whole body, and that they commence in fine hollow processes in the ramified nuclear fibre-cells of that tissue, which are also supposed to be hollow. But these views have not been confirmed.

As the commencing lymphatics are generally most abundant in tissues in which the nutritive changes are not very active, and least abundant, or not detected, in organs which undergo very rapid metamorphosis, it is probable that the waste products of nutrition are chiefly, or, in the case of the nervous centres, entirely, returned into the circulation, through the capillaries and minute veins. It is probably correct to infer that the lymphatics do not remove wasted and excrementitious materials, unfit for the further use of the system, as Hunter formerly supposed, but rather that they take up matters which may be again employed in the blood, for the purposes of nutrition. The fibrin of the lymph, which enables that fluid to form a slight coagulum, though not in the vessels, as occurs with the blood, and also the lymph-corpuscles, which so closely resemble the white corpuscles of the blood, are present before the lymph has passed the lymphatic glands, but they increase in quantity beyond those glands. The fibrin may be partly derived from that portion of the nutritive plasma effused through the walls of the capillaries, which is absorbed by the commencing lymphatics; its gradual increase in quantity in the larger lymphatics may depend on inspissation, or enrichment, taking place within the glands, which are very vascular; additional *fibrin* or *fibrinogen*, from which the fibrin is formed, may even be elaborated in these glands. The lymph corpuscles may also be, in some way, more abundantly developed within the glands, which must, more or less, retard the rate of motion of the lymph. The outer areolar spaces of the glands, which receive the lymph as it enters, contain numerous corpuscles and granules, some of which are probably added to the moving stream of lymph. But such corpuscles are undoubtedly formed, though in smaller number, independently of the glands; for they may be detected in both the lymphatic and lacteal vessels, *before* these have passed through glands; also in the lymphatic vessels of the hind limbs of birds, on which no lymphatic glands are found; and likewise, in the lymph of Reptiles, Amphibia, and Fishes, although in these animals no lymphatic glands exist at all, but only complex or simple lymphatic plexuses. The destination of the lymph corpuscles is the blood; they probably constitute in the Vertebrata, after birth, the chief, if not the only source of the white corpuscles of the blood, as will again be mentioned in the Section on Sanguification.

Absorption of the Food.

The absorption of the digested food is only a special example of the general absorptive function. It has been maintained by some, that the nutritive constituents of the food are absorbed from the alimentary canal by the *lacteals* only; by others, that this absorption is accomplished by the minute *bloodvessels* alone; but both sets of vessels are concerned in this function, each apparently performing special offices.

That the *bloodvessels* of the alimentary canal absorb, has been thus proved. Strychnine has been introduced, in a living animal, into a portion of intestine, included between two ligatures, and separated from the mesentery, excepting by its arteries and veins; so long as the circulation through the intestine is arrested by compression of the bloodvessels, no symptoms of poisoning occur, but when the blood is allowed to flow through the vessels, the animal is speedily poisoned. Moreover, certain alimentary substances, such as albuminose, dextrin, sugar, and lactic acid, have been found in the blood of the mesenteric veins; many chemical substances, especially metallic salts, and those which easily penetrate animal membranes, as *e.g.*, the ferro-cyanide of potassium, when taken with the food, have been detected in the venous blood, and even in the secretions; so also odorous substances, such as musk, camphor, and garlic, alcohol, and soluble coloring matters, as *e.g.*, cochineal and madder, taken into the stomach, have been found in the blood. Even *insoluble* substances, such as charcoal, sulphur, and it is said starch, taken internally, in a state of minute subdivision, have been detected in the mesenteric veins.

The entrance of nutrient and other matters from the intestinal canal into the *lacteals*, is proved by the distension of those vessels with white chyle, during digestion, especially after ligature of the thoracic duct. The chemical composition of the chyle (p. 80), shows that, besides absorbing the water of the food, the lacteals take up small quantities of saline substances and extractives, a certain quantity of the albuminose products of digestion, and, in particular, a very large amount of fatty matter. With regard to non-nutrient substances, however, the absorptive power of the lacteals is much more limited than that of the veins. First, with regard to poisons: in experiments, the opposite of that just recorded, the arteries and veins of a piece of intestine, isolated by two ligatures, have been tied, whilst the rest of the mesentery, containing the lacteal vessels, has been left untouched; poison then introduced into the intestine is not absorbed, so as to destroy the animal, until, by loosening the threads on the bloodvessels, blood is again allowed to flow through them. (Magendie and Segalas.) To such experiments it has been objected, that tying the bloodvessels suspends the functions of the lacteals, which may lose their absorbing power when the capillary circulation around them is stopped. The experiment has, therefore, been varied, so as to permit the local circulation to continue; thus, the vein from the part of the intestine into which the poison is introduced, is first compressed, and then opened below the point of compression, so that the blood returning along it escapes, and does not enter the general circulation, although the local circulation in the intestine still goes on. Under these conditions, no poisoning takes place, but this speedily happens when the pressure on the vein is removed, and the blood returning by it, enters the general circulation. Nevertheless, poisons are slightly and slowly absorbable by the lacteals, especially poisonous salts in a state of solution. The lacteals also absorb innocuous saline matters, sugar, and extractive matters, but not so easily as the veins; neither do they so readily take up odorous substances; with regard to soluble coloring matters, turmeric is taken up by them, whilst other dissolved coloring substances, such as madder-lake, indigo, gamboge, and rhubarb, are said not to be absorbed. (Tiedemann and Gmelin.) Substances in a state of extremely minute subdivision, such as charcoal, sulphur, and even particles of indigo, have also been found in the lacteal vessels, as well as in the bloodvessels, having probably penetrated into those vessels in the villi.

From the preceding facts, it would seem that the absorbing power of the veins is *general*, whilst that of the lacteals is *select*. The veins permit the entrance into them indifferently, of probably all kinds of *soluble* substances, which do not actually alter or destroy the texture of their coats, but the lacteals have a sort of selective power, by which they take up certain substances in preference to others, nearly, or completely, rejecting some. Both kinds of vessels, but especially the lacteals, appear to allow, in some way or other, the entrance into them of exceedingly minute particles of insoluble substances, not by a process of dialysis, but by *porous diffusion*, the pores being, however, invisible in the walls of the capillaries or lacteals, though specially discernible, according to some, in the epithelial cells upon the villi. The direct penetration of the walls of the capillaries and lacteals, has been compared with that of a needle entering a larger vessel. A certain hardness of the penetrating particles is necessary, for lampblack, which is finer and softer than charcoal, does not enter the vessels. Penetration of the soft tissues, by minute bodies, without serious injury to the former, is illustrated by the wandering movements of the smaller Entozoa, through and amongst the living tissues.

By far the larger quantity of the water of the food and drink, and of the saliva and gastric juice, is taken up by the veins. This process begins immediately, and goes on rapidly, in the stomach; it regulates the consistence of the gastric contents, and the strength and acidity of the gastric juice; more water, including some of that belonging to the biliary, pancreatic, and intestinal secretions, is taken up by the veins of the intestines; but much is here absorbed by the lacteals, to form the fluid part of the chyle. The saline constituents of the food are absorbed directly, in chief part, by the veins, these substances, such as chloride of sodium and phosphate of soda, requiring, like water, no digestion; minute traces of them, however, also enter the lacteals. Sugar and extractive matters likewise enter chiefly by the veins, and but slightly through the lacteals. The organic acids, and their salts, are converted into carbonates, and undergo venous absorption. Alcohol also passes in chiefly, if not entirely, by the veins, and so likewise do the ethereal, odorous, sapid, and coloring matters of the food, and probably also most medicinal and poisonous substances. Venous absorption even begins in the mouth, as may be inferred from the occurrence of taste; but it is much more active in the stomach and intestines. Soluble albuminoid substances, if not converted into albuminose, may be absorbed directly by the veins of the stomach and small intestine, and certainly by those of the large intestine, as is exemplified in the restorative effects of nutrient enemas. The soluble albuminose, the product of digested albuminoid bodies, must also be in part absorbed by the veins; for the quantity of albumen taken up into the chyle is scarcely equal to that contained in the food. The gelatin-peptone probably enters the veins. Lastly, fatty matters have not been directly proved to be taken up by the veins, though, if in a saponified condition, they may be so, and the capillary network has been seen to assume a turbid appearance, as if containing fat. (Brücke.) Besides this, in cases of disease, not only the coloring substances, but the fatty matters of the bile, enter the circulation through the venous system. The chief channels of entrance of the fatty matters emulsified during the process of digestion, are, however, the lacteal vessels, as is proved by the large proportion of fat in the chyle.

The veins thus absorb most of the water, and of the saline, saccharine, extractive, acid, alcoholic, odorous, sapid, and coloring substances, together with some albumen or albuminose, probably the gelatin peptone, and possibly saponified fatty matters. On the other hand, the lacteals absorb the rest of the water, small quantities of the saline, saccharine, and extractive substances, a considerable proportion of the albuminose bodies, and nearly all the fat. In the intervals between the absorption of food, the lacteals of the small intestine, like the lymphatics of other parts of the body, contain only a transparent lymph, and then perform, for the tissues of the intestine, the office of lymphatics generally. The same is true, at all times, of the lymphatics of the stomach and of the large intestine, which never contain chyle, but always lymph.

It may be presumed that the absorption which takes place from the stomach, is chiefly performed by means of the bloodvessels, because the gastric mucous membrane is destitute of villi, and, therefore, of proper lacteal vessels; nevertheless, nutrient and other substances, prevented from entering the intestine, by ligature of the pylorus, have been shown to be absorbed by the gastric lymphatics. The process by which certain parts of the food are absorbed by the *bloodvessels* of the alimentary canal, must be identical with that of the general absorption of soluble substances from other vascular surfaces, or tissues, of the body. Like the latter, it partakes of the nature of the physical processes of liquid diffusion and dialysis. Water, and substances dissolved in it, such as soluble salts, sugar, extractive matters, and soluble albumen or albuminose, permeate the epithelial and subjacent layers of the mucous membrane, and also the thin coats of the capillaries and smallest venules, not merely of the villi, but of the general surface of the intestinal canal, in the same manner, probably, as a similar solution would pass through moist dead animal membranes. The temperature of the interior of the body greatly favors the osmotic process. The penetration of the water with its dissolved contents, is a dialytic phenomenon; and by a similar action, the entrance of certain substances is probably permitted more readily than that of others, the crystalloid substances, such as the salts and sugar, with the creatin and creatinin of the extractive matters, and also the albuminose and gelatin peptones, entering more readily than the colloid substances, such as dissolved starch, mucilage, albumen, gelatin, and the non-crystallizable extractive matters. But dissolved colloidal starch is converted by the salivin into the crystalloid sugar; and albumen and gelatin, when digested by the acid pepsin, are changed into albuminose and gelatin peptones, which, though not true crystalloids, are much more dialyzable than the albuminoid and gelatinoid substances contained in our food. The molecular metastases, or changes in question, may be in some way connected with a process of *hydration*. It has also been suggested that a colloid body may be formed by groups of crystalloids, and so its temporary metastasis from one condition to another may be explained. It is possible also that there may be special reactions between alimentary substances and the living mucous membrane and walls of the vessels, favoring or resisting the passage of some or other of those substances. But this is uncertain; and the act of absorption by the bloodvessels is so easy, rapid, and general, in the case of non-nutrient, and even of many poisonous substances, that their walls can possess but little if any power of selection or exclusion. Fatty matters, however, unless in a state of saponification, do not readily, or at all enter the bloodvessels. Experiment has shown that even when finely divided, as they exist, for example, in the yolk of the egg, and in milk, they may be made, under moderate pressure, to permeate moist membranes (Heidenhain); and further, that the natural repugnance between oil and wetted membranes, is much overcome, if these latter are saturated in alkaline solutions or in bile. (Wistinghausen.) A temperature of 100°, or that of the interior of the body, facilitates this permeation of fat. Though acids generally, and especially the hydrochloric acid, which exists in gastric juice, are rapid dialyzers, and so penetrate very quickly the colloidal albuminoids of the food, which they help to dissolve, yet acidity appears to be opposed to the absorption not only of fat, but of actually dissolved substances; whilst a neutral or alkaline condition favors their absorption. In certain cases, especially in regard to organic substances of an extraneous, medicinal, or poisonous character, it appears that the digestive fluids not only dissolve, but also alter, the properties of substances taken into the stomach. Thus, there are two substances found together in the bitter almond, named *amygdalin* and *emulsin*, the former of which is decomposed by a catalytic action of the latter, and gives rise to the formation of prussic acid. Now, it has been found by Bernard, that amygdalin, introduced by itself into the stomach of any animal, is digested, dissolved, and absorbed, without giving rise to poisonous symptoms. Again, emulsin alone taken into the stomach produces no ill effects. If, however, after the absorption of the dissolved amygdalin from the stomach, emulsin be directly injected into a vein, death speedily ensues, from the formation of prussic acid in the blood or tissues, by the decomposition of the dissolved amygdalin under the influence of the emulsin, thus introduced into the circulation, and brought into relation with it. But on the other hand, if the emulsin be introduced into the stomach, and the amygdalin be injected into the bloodvessels, poisoning does not ensue, showing either that the emulsin is not absorbed from the alimentary canal, or that its properties are destroyed. The latter is, probably, the case, for emulsin is easily soluble, and when it and the amygdalin are introduced together into a vein, or even into distant parts of the circulation, their meeting in the blood is immediately followed by the characteristic decomposition of the one under the influence of the other, prussic acid being evolved, and the animal being killed.

After the absorbed materials have entered through the capillary walls, their onward progress depends upon the forces concerned in the circulation of the blood.

The process of absorption by the *lacteals* is of a more special nature than that by the bloodvessels; for though they admit the entrance, probably by simple dialysis, of water, with traces of saline, saccharine, and extractive substances, that is, of the crystalloid bodies, and also take up in certain proportion, the dialyzable albuminose, yet they are specially characterized by absorbing fatty matters, which, though crystalloid, are insoluble in water, and non-dialyzable, unless they are actually saponified. In the alimentary canal, however, they are merely liquefied, or emulsified, *i. e.*, reduced to a state of extreme molecular subdivision, or they are decomposed into their fatty acids and glycerin. The special power of the lacteals, of absorbing fatty matters, has not yet been fully explained. Some have supposed that the fats pass through the epithelial substance of the villi, into the lacteals, in a state of saponification and solution, and then reappear as neutral fats in the chyle. The action of the bile and of the alkaline pancreatic and intestinal juices, as already explained, undoubtedly prepares the fatty matters for more easy penetration into the lacteals. The epithelial cells of the villi, which are often found distended with drops of fat during the digestive process. are probably specially concerned in the absorption of fat by the lacteals. It has been supposed that these cells feed, as it were, upon the fatty matters contained in the intestine, and, having become distended, discharge their fatty contents into the commencing lacteals. A nutritive process is imagined to take place, similar to that which occurs in the epithelial cells lining the commencing ducts of the secreting glands, but in a *reverse* direction; that is to say, not by the assimilation of materials from the blood into these secreting cells, to be discharged at the surface, but by the assimilation of materials from the surface inwards, to be discharged into the lacteals. This fatty matter must enter the epithelial cells covering the villi, in the form of exceedingly minute molecules, by porous diffusion or transmission; and the fine vertical lines or streaks, noticed by certain observers in these cells (p. 604), are supposed by some to be minute pores or channels, through which the highly subdivided fatty matters, or even fine solid particles of charcoal, enter the interior of the cells, and so proceed into the lacteals. How the fat particles pass from the cells into the commencing lacteals is not known. By some it is said that the inner pointed ends of the epithelial cells, terminate in caudate areolar tissue cells, which, in their turn, communicate with the lacteals. But this is more than doubtful; and the actual transmission is probably by porous diffusion, through true but invisible pores.

The onward motion of the chyle, from the commencing lacteals in the villi, into and through the larger absorbent vessels on the walls of the intestine, and along the mesentery, to the thoracic duct, depends on several agencies. First, the chief cause is probably the *vis a tergo*, or *force from behind*, originating in the continuous nature of the absorptive process at the commencement of the lacteals. The existence of this force is proved by the distension of the whole system of vessels, including the thoracic duct, even to the occurrence of rupture, when that duct is tied in an animal a short time after it has been fed. This pressure from behind produces a motion of the fluid in the larger absorbents, just as the continuous absorption of fluid by the spongioles at the extremities of the roots of trees, causes the rising of the sap. Even in simple dialysis, in purely physical experiments, as with the endosmometer of Dutrochet, there is an ascending motion of the fluid in the graduated tube, due to the energy at work in the moist membrane. Secondly, the contraction of the non-striated muscular fibres of the villi, which, when stimulated by galvanism, in living animals, has been observed to shorten those processes, must compress the central lacteal of each villus, and so urge on its contents into the general network of absorbents. The bile may help to excite this muscular act. Thirdly, the contraction of the scattered muscular fibres in the submucous coat, and also the peristaltic movements of the proper muscular coat of the intestine, likewise excited by the food and by the bile, will serve to empty the intestinal lacteals into those of the mesentery. Fourthly, the lacteals and the lymphatics, as well as the thoracic duct, have muscular fibres in their coats, the contraction of which moves onwards their contents, and also empties them on their being exposed to the air, in animals recently fed; this explains the collapsed state of these vessels after death. There are also muscular fibres in the inter-alveolar septa of the lymphatic glands. Fifthly, the semilunar valves found in pairs in the interior of the larger lacteals, both in the walls of the intestine and in the mesentery, must determine the movement of the contained chyle, always in the same direction, by whatever force such movement may be induced. In this way, even the pressure of the abdominal walls and viscera must assist the onward flow of the chyle. Its direction necessarily coincides with that of the free margins of the valves, viz., towards the thoracic duct, all retrogression of the chyle in the direction of the intestine, being effectually prevented. Lastly, the quick motion of the blood in the great veins at the root of the neck, into which the thoracic duct opens, and the effects of inspiration, are also causes of a certain *vis a fronte*, or *force from before*, which draws the lymph or chyle from that duct into the veins. The descent of the diaphragm in inspiration, acts not only by removing pressure from the great veins in the thorax, but also by increasing the pressure on the abdominal lymphatics and the lower end of the thoracic duct.

The quantity of mixed lymph and chyle poured into the blood in twenty-four hours, has been estimated, from experiments in animals, to be, in an adult man, nearly 29 lbs., of which the smaller proportion is chyle, the rest being lymph. (Bidder and Schmidt.) It has been ingeniously suggested by Vierordt, that, if the absorption of fat be supposed to take place exclusively by the lacteals, and the composition of the chyle be assumed to be uniform, the daily quantity of chyle may be calculated from the daily quantity of fat taken in the food. Thus, the quantity of fat consumed in the day being taken to be 3 oz., and the chyle, to contain 3 per cent. of fatty matters, the quantity of this fluid formed daily would be about 100 oz., or $6\frac{1}{4}$ lbs. The chyle is a highly nutrient fluid. It adds not only fatty matter, but, like the lymph, a certain amount of fibrin or fibrinogen, albumen, extractives, and salts, and also a number of granules and proper corpuscles, to the blood. The *gradual* entrance of these into the blood, is of some importance in the maintenance of the proper composition of that fluid, and, accordingly, nutrient substances are absorbed rather more slowly than those which are not nutrient. The more concentrated the products of digestion, however, the more rapid is their absorption; at least this is true of sugar and albuminose. (Becker, Funke.)

Intrinsic Absorption.

The special process, by which the fluid or solid parts of the living body, are interstitially removed, the so-called *intrinsic absorption*, is usually described with the simpler phenomenon of general absorption. But it is a different and more complex process, implying a previous liquefaction, or fine disintegration, of the solid particles of the absorbed tissues, before these can enter the lymphatics or bloodvessels concerned in their removal. It is in part, therefore, a nutritive or *denutritive* process.

Intrinsic absorption is sometimes simply *interstitial*, accomplishing the removal of tissues, molecule by molecule, without any solution of continuity, or breach of substance, in them, the part affected becoming merely smaller, and not necessarily undergoing any special change of form. During simple interstitial absorption, nutritive changes, involving the deposition of fresh material, must still go on, but the process of absorption is relatively more active than that of the deposition of new matter. This kind of interstitial absorption is illustrated in the *wasting* which takes place as the result of hunger or starvation, and also in the disease known as *atrophy*.

Another form of intrinsic absorption, known as *progressive absorption*, involves more or less solution of continuity, or breach of substance. It is often apparently caused by pressure interfering with the nutrition of a part; it is exemplified in certain morbid processes, as when an aneurismal, or other deep-seated tumor, in approaching the surface, induces absorption of the interposed structures, even the bones being absorbed under the effects of constant pressure. Abscesses also tend to the surface of the body or of internal mucous cavities, by a similar progressive absorption. Another form of this process is named *disjunctive* absorption; in this, the living part of a tissue, in immediate connection with a dead portion, is removed by absorption, and so the dead part is detached; such a process occurs in the separation of a slough from a soft tissue, or of a necrosed or dead portion of a bone, from a living part, and also in the throwing off of a portion of the entire limb, as in the case of gangrene of the foot.

Certain tissues also undergo intrinsic absorption much more readily than others. Bone, one of the hardest tissues in the body, is very readily absorbed; its numerous Haversian canals, and cancelli, and even its general medullary cavities, are channels or spaces produced, during its growth, by an absorptive excavation of a previously solid osseous tissue; such changes occur in it, even when it is fully developed; and, as just now stated, it is very easily absorbed under abnormal pressure. The fangs of the temporary or milk teeth, which are composed of dentine, a substance more compact than bone itself, undergo progressive absorption under the influence of pressure from the summits of the rising permanent teeth, and, in this way, are loosened, and finally drop away from the gum. Cartilage is less easily absorbed than bone, but, nevertheless, it does yield to that process. The fasciæ, areolar tissue, skin, and mucous membranes, also give way under the progressive absorption caused by abscesses which are advancing to the surface; the epidermis and epithelium, however, burst mechanically. Vascularity is necessary for the occurrence of true intrinsic or progressive absorption. Cartilage is probably absorbed by closely adjacent vessels. All vascular organs and tissues are liable to progressive absorption under pressure, and all may undergo waste or atrophy.

In the progress of development, in Man and animals, many instances occur of the disappearance of parts not permanently needed, such as the temporary gills of the higher Amphibia, the tails of the tadpoles of the anourous species, and also certain large bloodvessels which are no longer required in more advanced conditions of development. The removal of the membrane which closes the pupil of the eye, when it is no longer needed for the vascular supply of the lens, is another instance of intrinsic absorption; so also are the many changes which take place in the jaws, during the formation of the sockets for the teeth, and their filling up when these are lost. Sometimes an entire organ of complex structure, with its proper parenchyma, bloodvessels, lymphatics, and nerves, becomes atrophied by interstitial absorption. Thus, the *thymus* body, a ductless gland, which exists in the forepart of the neck and thorax, in the young of Man, and the Mammalia generally, disappears as life advances. In the human body, the thymus exists only as a mere vestige, after the age of twelve years.

By the process of *resorption*, blood, lymph, dropsical effusions, pus, and other fluids, are easily taken up from the areolar tissue in which they are extravasated or effused. From the serous cavities, and especially from the joints, they are less easily resorbed. It is probable that the solid albuminoid constituents of such effused products, undergo a chemical change of degeneration, becoming converted into fatty matter, and some nitrogenous, perhaps ammoniacal compound, both of which are absorbable. It has been found that a piece of muscle introduced into the cavity of the peritoneum, first loses its water, and then gradually undergoes a fatty change.

When *inflammation* reaches a certain height, besides the exudation of plastic matter from the bloodvessels, and the formation of cells, which may end in the production of pus, or of new-formed tissue, the nutrition of the pre-existing tissue itself may suffer, and it may become slowly disintegrated, or undergo molecular death. It then falls away imperceptibly, and a chasm is left, called an *ulcer*, the process itself being named *ulceration*. Both the vascular and non-vascular tissues are liable to become ulcerated. It was once supposed that the formation of an ulcer, or the ulcerative process, began and continued by the interstitial absorption of an inflamed tissue, this form of absorption being named *ulcerative absorption;* but although a true absorptive process may occur in some forms of ulcer, there is little doubt that, generally speaking, the erosion of a living tissue, known as ulceration, is due to the molecular death and melting away of the tissues. Ulcers always occur on surfaces, whether in vascular parts, such as the skin, mucous membranes, and bones, or in non-vascular parts, such as the cornea and the articular cartilages.

There is reason to believe that both the *lymphatics* and the *bloodvessels* are concerned in the various forms of intrinsic absorption or resorption. The agency of the lymphatics is rather inferred from analogy, than demonstrated by facts. It is impossible to doubt that the bloodvessels are also concerned in it, for the phenomena may take place in parts in which lymphatics are not believed to exist, as, for example, in the brain; but the process is here undoubtedly much slower.

Intrinsic absorption is favored by continued moderate pressure, as by the use of surgical bandages, which, however, may also act by restraining the supply of blood and the nutrition of a part. It is also favored by an elevated position, by friction, and by stimulating applications. It serves important uses in the economy, enabling the whole system to be maintained, for a time, upon itself, and, by the absorption of fatty matter stored up in the adipose tissues, supporting the respiratory function, even in the absence of food. In the removal and casting out of diseased products, or dead parts, it also exercises a useful and conservative office.

In conclusion, it may be repeated that, in addition to these important uses, the function of absorption generally, ministers to the nutritive function, by the conveyance into the circulating system, not only of the materials of the food, but also of the residual part of the plasma of the blood, not immediately employed in the nutrition of the tissues amongst which it is poured out; and, lastly, that it assists in the elaboration of those essential organized elements of the blood, its white and its red corpuscles.

The Absorbent System, and Absorption in Animals.

A lymphatic and lacteal apparatus exists only in the Vertebrate Subkingdom. In all cases, the finest vessels commence by blind extremities, and the absorbent trunks empty themselves ultimately into the veins, forming, as it were, a closed system superadded to, or constituting an offset from, the blood system, with which, in the lower Vertebrata, it communicates at a great number of points, not only in the neck, but also in the abdomen and pelvis.

In Mammalia generally, as in Man, well-developed lymphatic glands are found; in the Carnivora, owing probably to the shortness of the intestine, the mesenteric glands are so closely aggregated, as to appear like a large conglomerate gland. In Birds, lymphatic glands are also found, especially in the forepart of the body, but they are less perfectly developed, and, in other parts, are replaced by elaborate plexuses of lymphatic vessels; in accordance with the general lateral symmetry of these animals, there are two thoracic ducts, each with its receptaculum chyli; in certain birds, as in the goose, dilatations of the pelvic lymphatics are met with, the coats of which are provided with unstriped muscular fibres, which do not contract periodically or rhythmically; the lymphatics of the hinder part of the body communicate very frequently with the veins. In Reptiles, the lymphatic glands are absent, but their place is apparently supplied by the great size and abundance of the absorbents themselves, and by numerous plexuses of closely-packed vessels; the valves are either imperfect, or are found only in the larger trunks; communications with the veins exist in the lower limbs. In this Class, as well as in the Amphibia and Fishes, there occur, connected with the lymphatic system, those remarkable rhythmically contractile sacs, known as *lymphatic hearts;* they have been found in the neck of certain Ophidia, and in the pelvis of the turtle and crocodile. In the Amphibia, the lymphatics are relatively large, but few in number; neither valves nor lymphatic glands exist; the lymphatic hearts, usually four in number, have walls composed of *striated* muscular fibres: in the frog, two of these hearts are situated, one on each side of the neck, opposite to the third cervical vertebra, and two posteriorly in the pelvic region. It is in Fishes that the absorbents are fewest in number; they are delicate transparent vessels, destitute of valves, excepting at the points of entrance into the veins, which are here very frequent: the lacteals appear almost destitute of distinct walls. In the tail of the eel, and in many fishes, behind the cranium, outside the jugular veins, there are found pairs of lymphatic hearts, or dilatations of a similar nature to the true lymphatic hearts of the Amphibia. No lymphatics have been observed in the amphioxus.

The chyle varies in color and opacity in different animals; thus, it is very milky-looking in the carnivorous, but almost colorless in the herbivorous Mammalia; it is also more transparent in the cold- than in the warm-blooded Vertebrata.

It is usually considered that no vessels homologous in character and office with the lymphatics and lacteals of the Vertebrata exist in Non-vertebrate animals; but it has been suggested that the so-called blood-system of the Mollusca and higher Annulosa, with its usually colorless contents, including corpuscles much more like the white than the red blood-corpuscles of the Vertebrata, may possibly be the homologues of the vertebrate lymphatic system. Be this as it may, these vessels are undoubtedly concerned, not only in the function of circulation, but also in that of absorption; for absorbed materials not only pass into the perivisceral cavity, and penetrate the soft tissues of the body, immediately and directly, but they also enter the interior of these so-called bloodvessels, mingle with the circulating fluid, and thus are conveyed to the most distant parts of the frame. Such vessels must be concerned both in the absorption of the food, and in all the phenomena of general extrinsic and intrinsic absorption. In those Non-vertebrate animals, which, as the Annuloida, possess the so-called water vascular system, or some analogous vessels, general absorption may be assisted by them. In the Cœlenterata, all of which are destitute of proper vessels, the fine tubular extensions of the body cavity into the soft disc, must aid in this process; but in the simple hydra, absorption must be accomplished by direct imbibition through the cells lining the digestive cavity, and by general percolation through the soft intercellular spaces. In the Protozoa, it must occur through the sarcodous cell-substance, of which those animals consist.

Whilst, therefore, in the lowest non-vascular animals, nutrient matters at once permeate the tissues which they have to nourish, and whilst, in all animals possessed of vessels, whether absorbent or circulating, or fulfilling both functions, a similar permeation of nutrient matter takes place through the lining membrane of the digestive cavity, yet, in the latter case, it has no immediate nutrient action on the solid tissues, but speedily passes into the bloodvessels or absorbents, and thus directly or indirectly enters the circulating fluid or blood. Mixed with this, it probably undergoes further elaboration, before it again transudes through the walls of the fine vessels, into the solid tissues, which are ultimately nourished by it.

CIRCULATION.

We have seen that the absorbent vessels end in the great veins at the root of the neck, and that there, the lymph and chyle are poured into the blood. The blood is not permitted to remain stationary in any part of the living body; but in order to fulfil its offices in the general functions of nutrition, secretion, and excretion, and its special office of stimulation in regard to the nervous and muscular systems, and in order that it may be constantly purified by the respiratory process, it is kept in continual motion throughout the whole of life. This motion of the blood takes place, in Man and in most animals, in distinct cavities and channels, viz., through the heart and bloodvessels, the arteries, capillaries, and veins. The movement itself is named, from its definitely recurrent course, the *circulation of the blood.*

The general distribution of the arteries, capillaries, and veins of the body, and the structure of these vessels, have already been explained pp. 25 and 54). The heart, or central organ of the circulation, requires now to be described.

The Heart.

The Heart and Bloodvessels.

The heart, inclosed in its sac, or pericardium, is placed obliquely in the thorax, between the lungs (Fig. 13), occupying a space about 4 inches in width. It is of a conical shape. Its base, connected with the large bloodvessels, is directed upwards, backwards, and to the right, corresponding with the middle of the dorsal region; its apex turned downwards, forwards, and to the left, points to the left of the sternum, opposite the interspace between the fifth and sixth ribs, two inches below and one to the sternal side of, the left nipple.

Its anterior surface, turned slightly upwards, is convex; its posterior surface, directed downwards, and supported by the diaphragm, is flattened. This organ is about the size of the closed fist. In the adult male it weighs from 10 to 12 oz., but from 8 to 10 oz. only in the female. Its proportion to the body, in the former sex, is as 1 to 169; in the latter, as 1 to 149. It measures about 5 inches in length, $3\frac{1}{2}$ in width, and $2\frac{1}{2}$ in thickness. It increases in weight, and enlarges in all its dimensions, as life advances.

The heart is a hollow muscle, its cavity being completely divided internally, by a longitudinal septum, into a right and a left lateral chamber. Each chamber consists of two cavities, one called an *auricle*, the other a *ventricle*, marked off from each other by a transverse constriction, which forms on the surface the *auriculo-ventricular* groove. The auricle and ventricle of the same side open into each other, but those of the opposite sides do not communicate. The two auricles are placed at the base of the heart; their walls are thin; they are separated from each other by the median septum, and receive blood from large veins. The two ventricles lie below the auricles, have walls of considerable thickness, and form the most solid part of the organ; each is connected with a large artery. Two longitudinal furrows, one anterior, the other posterior and less defined, correspond with the position of the median partition which separates the two ventricles within. The right ventricle occupies more of the anterior, and the left ventricle more of the posterior, surface of the heart; the left ventricle reaches lower than the right, and so forms alone the apex of the heart, the longitudinal furrows and septum terminating a little to the right of the apex. Each of the four cardiac cavities requires further description.

The *right auricle* (Fig. 105, 3) consists of a larger part, named the *sinus*, and a smaller part leading from it in front, named the *appendix auriculæ* or *proper auricle*, so called on account of its resemblance to a dog's ear. The margins of the appendix are notched, and its walls, instead of being thin and smooth, like those of the sinus, are thick, and marked internally by prominent fleshy bands, the *musculi pectinati*. Into this auricle the systemic veins open, viz., the *superior vena cava*, 1, at the upper and forepart of the sinus; the *inferior vena cava*, 2, at its lowest part; and, lastly, the large *coronary vein* at the back, its orifice being protected by a thin membranous valve, the *coronary valve*, or *valve of Thebesius;* besides this, there are numerous apertures of small veins belonging to the heart, and certain recesses in the auricular walls. Upon the septum, between this and the left auricle, is an oval depression, the *fossa ovalis*, bounded above, and at the sides, by a margin named the *annulus ovalis*. The fossa ovalis is the vestige of an opening, the *foramen ovale*, which exists before birth, then permitting the blood to pass from the right into the left auricle: sometimes the foramen ovale is not entirely obliterated, in that case, a small valved aperture leading obliquely, beneath the annulus ovalis, into the left auricle. Attached to the anterior margin of the orifice of the inferior vena cava is a thin membranous semilunar fold, called the *Eustachian valve* (Fig. 105), the free concave border of which is

Fig. 105.

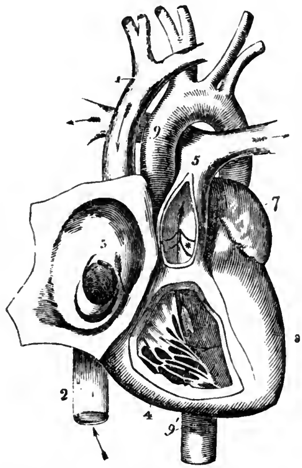


Fig. 105. Diagram of the heart and great bloodvessels. The right cavities of the heart, or right auricle and ventricle, and the pulmonary artery, are supposed to be laid open. 1, the superior vena cava; 2, inferior vena cava; 3, right auricle, laid open, showing the orifice of the superior and inferior cavæ. the latter guarded by the Eustachian valve; 4, right ventricle, laid open, showing the anterior segment of the tricuspid valve, its chordæ tendinæ, and musculi papillares. The thin walls of the auricle, and the thicker walls of the ventricle, are seen on their sections; 5, pulmonary artery, laid open, to show parts of two of its semilunar valves *; 7, part of the left auricle: the pulmonary veins are not represented, being concealed at the back of the heart; 8, the left ventricle; 9, the aorta, giving off branches to the head and upper limbs, and arching down to form the abdominal artery, which supplies branches to the rest of the body. The arrows show the course of the blood from the veins, 1. 2, to the right auricle; 3, through the auriculo-ventricular opening into the right ventricle, 4, and thence along the pulmonary artery, 5.

turned upwards and to the left; it is often small, frequently perforated, and sometimes wanting. Before birth, it is large, and of great importance in directing the course of the blood. Lastly, in front and to the left of the opening of the inferior cava, is the large aperture leading into the right ventricle, named the *right auriculo-ventricular* opening.

The *right ventricle*, 4, forms a somewhat conical cavity, shut off from the left ventricle by the thick interventricular septum. At its base is the opening from the auricle just mentioned, whilst above, and in front of this, is the aperture leading into the *pulmonary artery.* That portion of the ventricle conducting to the artery, forms a conical prolongation, named the *infundibulum* or *conus arteriosus.* Both of these openings are guarded by remarkable valves. The auriculo-ventricular opening corresponds with the middle of the sternum, on a level with the third intercostal spaces and fourth costal cartilages. It is somewhat oval, and measures about 1½ inch in diameter, in the male. It is surrounded by a strong fibrous ring, and its valve being composed of three pointed segments, is hence called the *tricuspid valve.* These segments, of a trapezoidal shape, are formed by a doubling of the lining membrane of the heart, inclosing bands of fibrous tissue, and, it is said, a few muscular fibres; the segments are continuous at their base, and are there fixed to the fibrous ring around the opening into the auricle (Fig. 106 *a*, 2). Of the three segments, one corresponds to the front of the ventricle, another to its posterior wall, and the third, the largest, lies between the auriculo-ventricular opening and the pulmonary artery. Each segment is thicker at its centre; whilst its margins are thinner, more transparent, and indented. To the margins, and also to the ventricular surfaces of the segments, are attached numerous fine tendinous cords, the *chordæ tendineæ* (Fig. 105), the other ends of which are connected either with certain muscular *columns*, to be presently described, projecting from the walls of the ventricle, or with the inner surface of that cavity, especially with the septum. The chordæ tendineæ, proceeding from the adjacent margins of any two segments of the valve, are connected with the same muscular column. Some of the cords are inserted into the base of the segments, others are connected with its central thicker part, whilst the finest and most numerous are inserted into its thin marginal portion.

The muscular bands just mentioned, named the *columnæ carneæ*, are found in nearly every part of the inner surface of the ventricle. They are of three kinds: first, some which form merely irregular, and frequently reticulated, prominences on the sides of the cavity; a second kind are adherent at each end, though free in the middle; lastly, a third kind, considerably larger than the others, and named the *musculi papillares*, form three or four bundles, which project upwards from the walls of the ventricle, and are connected with some of the chordæ tendineæ of the tricuspid valve. The internal surface of the infundibulum is smooth.

The orifice of the pulmonary artery, Fig. 105, 5, corresponds with the upper border of the third left costal cartilage, and second intercostal space, close to the sternum. It is circular, and measures, in the male, a full inch in diameter. Its protecting valves consist of three semicircular membranous folds, named *semilunar valves* (Fig. 105 *, Fig. 106, 4), attached, by their convex margins, to the sides of the pulmonary artery at its line of junction with the ventricle, but free at their straight borders, which are turned upwards in the direction of the artery. In the middle of the free border of each valve is a small fibro-cartilaginous nodule, the *corpus Arantii.* When stretched across the vessel, the borders meet each other, forming lines diverging from the centre at angles of 120°. The free and attached margins of each valve contain tendinous fibres; tendinous fibres also radiate across the valve, from the corpus Arantii to its attached margins, so that two thin semilunar portions, called *lunulæ*, are left, one on either

Fig. 106.

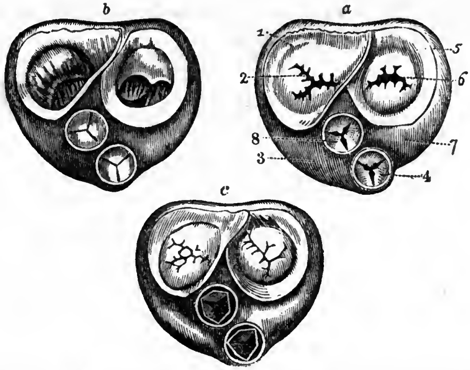


Fig. 106. Three views of the base of the heart, after removal of the auricles; the commencements of the pulmonary artery and the aorta are left, in order to show the valves of the heart and their altered positions at different moments of the heart's action. *a*, 1, interior of part of the right auricle; 2, right auriculo-ventricular, or tricuspid valve; 3, right ventricle; 4, pulmonary artery and its semilunar valves; 5, interior of part of the left auricle; 6, left auriculo-ventricular, bicuspid, or mitral valve; 7, left ventricle; 8, aorta, and its semilunar valves. In this view, all the valves have their segments a little apart. *b*, shows the auriculo-ventricular apertures open, and their valves apart; the arterial orifices are closed, and their valves in contact: condition during diastole of the ventricles. *c*, shows the opposite conditions of the valves; condition during systole of the ventricles.

side of the nodule. Behind the segments, the pulmonary artery presents, at its base, three slight dilatations or pouches, the *sinuses of Valsalva.*

The *left auricle* (Fig. 105, 7), somewhat smaller than the right, has thicker walls, measuring, on an average, $1\frac{1}{2}$ line in thickness, whilst those of the right auricle measure only 1 line. Like the latter, it consists of a *sinus* and an *appendix.* The sinus is placed behind the aorta and pulmonary artery. The appendix, projecting forwards and to the left side, is narrower, and more curved and notched, than the right one; its *musculi pectinati* are smaller and less numerous. At the back of the auricle are the openings of the four *pulmonary veins*, two on each side, their orifices being destitute of valves. On the septum, between this and the right auricle, is a lunated depression, bounded below by a crescentic ridge, the vestige of the foramen ovale. At the lower part of the auricle is the opening into the left ventricle, or left *auriculo-ventricular* opening.

The *left ventricle*, 8, is longer, and more conical in shape, than the right ventricle; it has much thicker walls, the proportion being as 3 to 1. The walls are thickest opposite the middle of the cavity, and thinnest at the apex, whilst the right ventricle is thickest near its base. The average thickness, in lines, of the walls of the two ventricles in the male, in whom they are somewhat thicker than in the female, are, for the left ventricle, at the base, middle, and apex, $4\frac{1}{2}$, $5\frac{1}{6}$, and $3\frac{3}{4}$; and for the right, $1\frac{5}{16}$, $1\frac{3}{8}$, and $1\frac{1}{30}$ (Bizot). The left ventricle increases in thickness as life advances; but the right remains unaltered after the period of full development.

At the left and hinder part of the base of this ventricle, is the oval opening from the left auricle; in front and to the right of this, is the circular aperture of the *aorta*. These openings are, after death, smaller than the corresponding orifices on the right side of the heart. The annexed Table shows the circumference of all four apertures, in the adult male and female (Peacock):

		Male.		Female.	
		Inches.	Lines.	Inches.	Lines.
Auriculo-ventricular openings,	right, ...	4	6	4	0
	left, ...	3	7	3	10
Arterial openings, ...	pulmonary, . .	3	4	3	3
	aortic, ...	3	0	2	10

The left auriculo-ventricular opening corresponds to the centre of the sternum, reaching upwards a little to the left. It is guarded by a valve, resembling the tricuspid valve, but formed of two segments instead of three, and hence called the *bicuspid* or *mitral valve* (Fig. 106, 6). The two segments are named, from their relative position, anterior and posterior; the former is somewhat the larger. The segments are provided with *chordæ tendineæ*, fewer in number than those of the tricuspid valve, but having similar attachments; all these structures are stronger and thicker than those of the right ventricle. The internal surface of the left ventricle generally, like that of the right, is provided with three kinds of *columnæ carneæ*, which, however, are relatively small and numerous; there are only two *musculi papillares*.

The round orifice of the aorta lies behind the junction of the third left costal cartilage with the sternum. It is separated from the auriculo-ventricular opening by the base of the anterior segment of the bicuspid valve, here joined to the aortic fibrous ring. The aortic orifice is protected by three *semilunar valves* (Fig. 106, 8, Fig. 107, *b*, 2), resembling those of the right side in form, in their mode of attachment to the sides of the great bloodvessel, and in the peculiar direction of their free edges towards the artery; but they are thicker and stronger, have their *corpora Arantii* larger, and their lunular margins more developed. The pouches, or *sinuses of Valsalva*, at the base of the aorta, are also larger than those of the pulmonary arteries. The two coronary arteries, or nutrient arteries of the heart, arise from the bottom of two of these pouches, close behind the corresponding semilunar valves.

The cavities of the heart are lined by a very fine serous membrane, named the *endocardium*, which is continuous with the lining membrane of the large vessels; it is somewhat thicker in the auricles than in the ventricles, and thicker in the left than in the right cavities; the valves of the heart consist essentially of folds of this membrane, inclosing fibrous tissue. It is difficult to determine the capacity of the cavities of a muscular organ like the heart; the estimates given of the capacity of the left ventricle, vary from 4 to 6.3 oz.; the right ventricular cavity is usually said to be a little larger. The capacity of each auricle corresponds with, or is a little smaller than, that of the respective ventricle.

The muscular fibres of the heart.—The *substance* of the heart is almost entirely composed of *muscular fibres,* arranged in layers, cov-

Fig. 107.

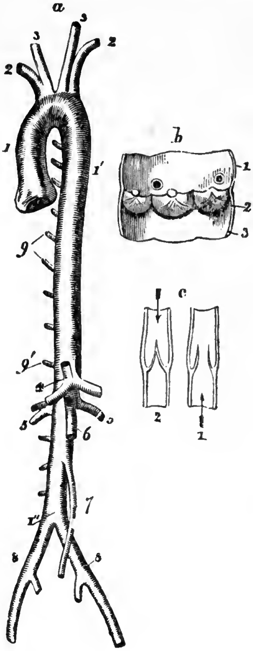


Fig. 107. *a*, the aorta, detached from the heart and from the body. 1, ascending aorta, showing the enlargements or pouches at its commencement, known as the sinuses of Valsalva: 1′, 1″, descending aorta, thoracic and abdominal; 2, 3, 3, 2, branches from the arch of the aorta, which supply the head and upper limbs; 4, cœliac axis, or artery, which divides into three branches to supply the stomach, liver, and spleen; 5, renal arteries, for the kidneys; 6, superior, and 7, inferior mesenteric arteries, which supply the small and large intestine; 8, 8, iliac arteries, which give off branches to the pelvis and lower limbs; 9, 9′, intercostal and lumbar arteries, which supply the walls of the thorax and abdomen. *b*, portion of the left ventricle, and the commencement of the aorta, laid open, to show the aortic semilunar valves; 1, portion of the aorta, with the orifices of the coronary arteries, or nutrient arteries of the heart; 2, the three valve segments; 3, portion of the left ventricle. *c*, diagrams, to show the action of the valves in the veins; 1, the valves open, so that the blood can pass on; 2, valves closed, so that the backward flow of the blood is arrested.

ered externally by a reflection of the serous membrane of the pericardium, and lined, within the cavities, by the endocardium. Four fibrous rings also exist, viz., those around the two auriculo-ventricular openings and the orifices of the pulmonary artery and aorta. Besides this, the heart possesses proper arteries, capillaries, and veins, deep and superficial lymphatic vessels, and numerous nerves and nervous ganglia.

The fibrous rings of the left side of the heart are, like the valves, stronger than those of the right side. Those of the auriculo-ventricular orifices give attachment to the segments of their respective valves, and also to a few of the muscular fibres of the auricles and ventricles. The rings surrounding the orifices of the pulmonary artery and aorta present a smooth ventricular border, attached to the muscular substance of the ventricles; and a deeply notched arterial border, with which the pouches of Valsalva are connected. When the heart of an animal is boiled, so as to harden its muscular, and to gelatinize its fibrous, portions, the auricles and great bloodvessels may be easily separated from the ventricles; three apertures only are then seen in the muscular substance of the base of the ventricles, viz., one for the left auriculo-ventricular opening, another for the orifice of the pulmonary artery, and a third, the largest, common to the left auriculo-ventricular opening and the aortic orifice; for the fibrous rings around these two latter are conjoined at one point. Behind the aortic orifice, and between the two auriculo-ventricular openings, is a piece of fibro-cartilage, which, when ossified, forms the *bone of the heart.*

The heart, though an involuntary muscle, has dark red fibres, marked with transverse striæ, like those of the voluntary muscles; but they differ, in being often branched and joined together again, and in having their fasciculi interlaced; moreover, the fibres are somewhat smaller, less distinctly striated, sometimes marked by faint longitudinal streaks, and, for the most part, are not attached to tendinous structures: the sarcolemma of each fibre is not easily seen, excepting in fatty degeneration of the fibres. There is scarcely any areolar tissue between the fibres, hence the characteristic firmness of the contracted heart.

The arrangement of the muscular fibres of the heart is one of the most difficult subjects of investigation. Vesalius, Albinus, and even Haller, were unable to follow them; and very different and complicated descriptions of the fibres have been given by Lower, Winslow, Senac, Wolff, Gerdy, Duncan, Reid, Budge, and, more recently, by Pettigrew.

After long boiling or maceration in pure alcohol, the fibres of the auricles, but especially those of the ventricles, may be stripped off, and unwound in flat bands or *layers.* The auricular and ventricular fibres are quite independent, the auriculo-ventricular fibrous rings, with the pericardium and endocardium, forming the sole bond of union between them.

The fibres of the *auricles* consist of a superficial and deep layer. The *superficial* layer is thin, incomplete, and common to both auricles; its fibres are transverse, and chiefly found on the front of the auricles; a few enter the septum. The *deep* layer consists of looped and annular fibres proper to each auricle; the *looped* fibres are fixed, by both ends, to the corresponding fibrous ring, and pass, in various directions, over the surface of the auricle; the *annular* fibres embrace the auricular appendages, and also surround the large venous openings in each auricle, extending both over the auricle and the veins.

The fibres of the *ventricles*, first studied by Lower (1669), present a far more complex arrangement. They present numerous, and somewhat easily separable, layers, having a general spiral arrangement around those cavities. The superficial fibres pass, more or less obliquely, downwards from right to left, on the front of the ventricles, and, in the opposite direction, *i. e.*, upwards from right to left, at the back of the ventricles. A few of these fibres are almost vertical. On the posterior or under surface of the heart, many of the superficial fibres are common to both ventricles, passing from one to the other, over the line of the septum, the surface being flattened, and the two ventricles blended together. On the upper surface, or in front, however, a great number of the superficial fibres dip in at the line of the septum, decussating with each other, so that the ventricles are here more distinct; nevertheless, some of these fibres pass from one ventricle to the other. When these are removed, the deeper fibres are found to be chiefly proper to each ventricle; so that, as said by Winslow, the ventricular portion of the heart seems to be composed of two hearts, enveloped in a third. As the fibres become deeper, they are less and less oblique, until, at last, they are nearly transverse, excepting such as ascend on the inside of the ventricles. According to their mode of dissection, different anatomists make different numbers of layers, and some divide these into numerous component bands. According to Pettigrew, the latest authority, there are *seven* layers, three outer ones, the fibres of which become successively less and less *oblique* downwards from right to left, a central *transverse* layer, and three inner ones, the fibres of which become more and more *oblique* in the opposite direction.

The ventricular fibres, whether superficial or deep, have long been known to form spirals, at and near the apex of the heart, the superficial fibres forming a completely closed spiral, and each succeeding layer a more open one. Hence, on looking directly at the apex of the heart, a remarkable whorl, or vortex, of fibres is seen, in which these appear, in turn, to sink towards the interior of the ventricles; if the fibres of each layer be now raised up and removed, the vortex becomes more and more open, and at length the cavities of the ventricles are exposed.

It was believed by Lower, Gerdy, Reid, and other anatomists, that the ventricular fibres chiefly, if not entirely, arise from the auriculo-ventricular fibrous rings, and that, after passing spirally round the heart, they turn upon themselves at the apex, there forming, as indicated especially by Lower and Gerdy, twisted continuous loops, and then pass up directly through the walls or septum of the ventricles, back to the fibrous rings again, or reach them indirectly, through the musculi papillares and chordæ tendineæ of the tricuspid and bicuspid valves. In short, the fibres of the ventricles were described as forming loops, open towards the base of the heart, but closed, and twisted into a vortex, at the apex. However, according to Duncan, the fibres form loops in the direction of the base, as well as in that of the apex; and Pettigrew affirms that none, or almost none, are attached to the fibrous rings, but pass by them, in the form of loops. Moreover, the elaborate dissections of the last-named anatomist show, that just as, at the apex, the superficial fibres penetrate, to become, as has been long known, the deep-seated fibres, so, at the base, the superficial fibres are likewise continuous with the deepest fibres.

In the left ventricle, which Pettigrew regards as the typical ventricle, the first, or superficial layer, passes, both at the apex and base, into the innermost or seventh layer, the second into the sixth, and the third into the fifth; the fourth layer is central, and forms a transverse layer situated between the third and fifth. Each successive double layer incloses the next in order, and the necessary limitation of the central layer, and its absence at the apex and base, account for the greater thickness of the walls of the left ventricle, across its middle. The spiral fibres, which may be traced from the front of the auriculo-ventricular opening, pass over the anterior surface of the ventricle, and, after describing one turn and a half, dip into the apex posteriorly; whilst those coming from the back of that opening, pass over the hinder surface of the ventricle, wind forward, and enter the apex anteriorly; after dipping inwards, the former end in the anterior musculi papillares and columnæ carneæ, and the latter, in the posterior musculi papillares and columnæ carneæ. The spiral and interwoven arrangement of all these layers, must assist the powerful and simultaneous contraction of the ventricular walls, and may perhaps explain the rotatory movement of the heart during each beat, to be hereafter noticed.

The structure of the right ventricle is similar, but less complete. Internal to the fourth layer, the fibres of the one ventricle are altogether independent of those of the other. The layers of the right ventricle are continued into each other, not at the apex only, as in the case of the left ventricle, but also along the whole length of the septum. The right ventricle is regarded, by Pettigrew, as a sort of segment of the left one, and he refers to the shape and perfection of structure of the latter, and also to the position, and the mode of development, of the septum, from a protrusion of the anterior wall of the single ventricle of the primitive heart, as according with this view.

The ventricular fibres, in the hearts of the Mammalia generally, seem to be arranged on the same plan as that of the human heart, and a correspondence is observed in the disposition of these fibres in the Bird, Reptile, and Fish.

The nutrient arteries of the heart are the two *coronary arteries*, the first branches given off from the aorta; they arise just beyond the semilunar valves, wind round the auriculo-ventricular groove, and give off two chief branches, which run along the furrows between the ventricles. The *cardiac veins* end chiefly in a short trunk, named the *cardiac sinus*, which opens into the back of the right auricle, and is protected by the valve of Thebesius, already described; this sinus is interesting, as being the persistent portion of the lower end of the left descending vena cava of the early embryo, the remainder of which closes from the root of the neck down to this sinus, leaving only certain vestiges behind. Numerous small cardiac veins enter the right auricle by separate openings. It has been supposed by some, that the blood may pass directly from the cavities into interstices in the tissue of the heart, and this appears to be the case in the heart of the frog and of certain Fishes, in which only one ventricle exists, containing a uniform fluid; but this could hardly occur in the hearts of the warm-blooded Birds and Mammalia, in which there are two separate ventricles, one containing dark or impure blood. In these, ample provision exists, in proper arteries, capillaries, and veins, for a special nutrient circulation. The *lymphatics* are superficial (Fig. 101) and deep. The *nerves* of the heart are derived, on each side, from the pneumogastric nerves, and from the sympathetic system. The former give off cardiac branches from their trunks, and also from their recurrent laryngeal branches; whilst the latter give off sympathetic cardiac branches from the cervical ganglia. The phrenic nerves send offsets to the pericardium, and possibly a few fibres to the heart itself. The sympathetic and pneumogastric branches unite to form the *cardiac plexuses*, from which small plexuses and branches proceed along the coronary arteries. Certain important ganglia exist upon the heart; the *ganglion of Wrisberg* lies beneath the arch of the aorta, and in animals, as in the calf and frog (Remak), others are found about the base of the ventricles. In the course of the cardiac nerves, certain enlargements have been described as microscopic ganglia (Lee); but according to other anatomists, these are thickenings of the sheaths of the nerves. The lining membrane of the sinus of the right ventricle, is most abundantly supplied with nerves.

Course and Causes of the Circulation.

In moving through the human body, the blood takes the following definite *twofold* course, the circulation in Man, like the heart itself, being *double.* Proceeding from the left side of the heart through the aorta (Fig. 108, 9, 9), and its various branches, called the systemic *arteries*, the blood is distributed to every part of the frame, reaching the *capillary vessels* throughout the body generally; from these capillaries, it passes into the minute venules, and collected into larger and larger *veins*, 1, 2, finds its way back to the right side of the heart, 3, 4: this part of the circulation is called the *greater* or *systemic circulation.* From the right side of the heart, 3, 4, the blood issues through the *pulmonary artery*, 5, and by its branches is conveyed to the lungs, passes through the *pulmonary capillaries*, is collected by the *pulmonary veins*, 6, and so returns once more to the left side of the heart, 7, 8: this part of the circulation, is called the *lesser* or *pulmonary circulation.* In the systemic circulation, therefore, the blood leaves the left side of the heart, and returns to the right side; in the pulmonary circulation, the blood leaves the right side and returns to the left. The left side of this organ, is sometimes called the systemic, and the right side the pulmonary heart. The greater circulation being performed through the body generally, and the lesser circulation through the lungs, the two are continuous, at the heart, with each other, a given portion of blood passing first through the one, then through the other, afterwards through the former again, and so on. The *portal* circulation, already described (p. 533), is a special offset of the systemic circulation.

The history of the discovery of the Circulation, affords a good illustration of the slow and labored steps by which man arrives at true knowledge. By Hippocrates, 400 B.C., the veins and arteries were confounded under one name, φλεβὲς, *phlebes*, the word *artery*, being applied by him to the *trachea* or windpipe. Aristotle distinguished the arteries from the veins, and noticed that the former were usually found empty of blood, containing only air: the heart, however, was known by him to be in connection with the veins, and these were supposed to convey the blood *into* the body. Galen was the first to maintain that the arteries contained blood as well as air. Vesalius pointed out that the two sides of the heart have no direct communication. Servetus demonstrated the passage of the blood through the lungs. The term "circulation" first occurs in the writings of Cæsalpinus, who had access to a treatise by Servetus. At length, in 1628, William Harvey published in his work, "*De motu cordis et sanguinis*"—on the motion of the heart and blood—an account of his great discovery, or demonstration of the real course of the blood, or of the Circulation.

He founded his conclusions, first, on the anatomical connections and continuity of the heart, arteries, and veins; secondly, on the facts, that on dividing an artery, blood issues from that end which is still connected with the heart, whilst on dividing a vein, the blood comes from the end furthest from the heart; thirdly, on the fact that a vein, when tied, swells on the side of the ligature furthest from the heart; and lastly, on the direction of the valves in the veins, and of those

Fig. 108.

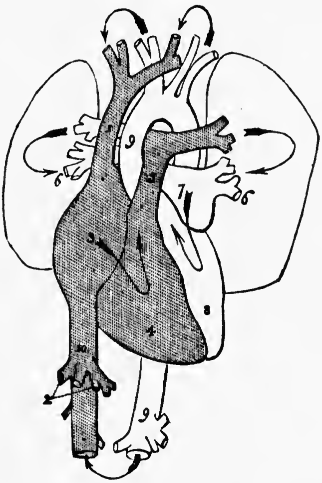


Fig. 108. Diagram of the cavities on the two sides of the heart, to show the course of the blood through it. 1, Vena cava superior; 2, vena cava inferior; 3, right auricle; 4, right ventricle; 5, pulmonary artery; 6, 6, pulmonary veins, right and left; 7, left auricle; 8, left ventricle; 9, aorta; 10, hepatic veins. The dark parts are those which contain venous blood; the light parts contain arterial blood. The arrows indicate the course of the blood within the heart, and through the lungs and the body. Thus, the dark blood returns from the upper half of the body by the superior vena cava, 1, and from the lower half of the body by the inferior vena cava, 2, joined by the hepatic veins, 10; it enters the right auricle, 3, passes into the right ventricle, 4, and then through the pulmonary artery, 5, and it branches through the capillaries of both lungs. Here, it is changed into red blood; gathered then into the pulmonary veins, 6, 6, it enters the left auricle, 7, passes into the left ventricle, 8, and thence through the aorta, 9, and its branches, into the capillaries of all parts of the body. Here it again becomes dark, and is once more returned by the venæ cavæ, 1, 2, to the right side of the heart. It is seen that the right and left sides of the heart do not communicate. The one always contains dark, the other red blood.

situated in the heart itself. Afterwards, the mode in which the blood passes from the arteries into the veins, not quite understood by Harvey, was explained by Malpighi's discovery of the capillary vessels, in the frog's foot, in 1661.

The *proofs* of the circulation of the blood, now usually advanced, are identical with those just mentioned, viz., the anatomical connection and continuity of the heart, arteries, capillaries, and veins; the different direction in which the blood escapes from a cut artery and a cut vein; the effect of ligature upon the veins; the special direction of the valves of the heart and veins; and lastly, the actual observation of the blood moving in the capillary vessels of the transparent parts of animals, such as the translucent bodies of the larvæ, or young, of Amphibia and Fishes, the gills of the tadpole, the web of the frog's foot, the mesentery of the mouse, the wing of the bat, and even the retinæ of our own eyes.

The chief *cause* of the motion of the blood, is the contraction of the muscular walls of the heart upon its fluid contents. But the movement of the blood is modified by the elasticity and muscular contractility of the coats of the arteries; it is aided by the pressure of the muscles of the body upon the veins, and likewise, to a certain degree, by the movements of the walls of the chest in respiration. Perhaps also the changes incidental to nutrition, secretion, excretion, and respiration, which occur in the blood, in the systemic and pulmonary capillaries, may influence its motion through them. The *direction* of the blood-current, is primarily determined by the valves within the heart, and is aided by those within the veins.

Action of the Heart.

The heart, the great agent concerned in the circulation, propels the blood from its interior, into the body and lungs, by means of successive contractions of its ventricular walls. The contractility of its muscular tissue is the immediate source of the motor power which impels the blood through the body. The suspension of the heart within the smooth pericardium, facilitates its movements; whilst the equally smooth endocardium diminishes the friction of the blood against the walls of its cavities. The heart has been likened to a force-pump, but this is a rude comparison; for a pump is a passive apparatus, through which some extrinsic force operates; whereas the heart, alternately dilating and contracting, first receives the blood from the veins, and then drives it into the arteries, by means of a force resident in its own walls. In this action, the right and left auricles dilate and contract together; and the right and left ventricles dilate and contract together. The contraction of the two ventricles always takes place immediately after that of the two auricles; and when the ventricles have contracted, an interval, or *pause*, occurs, before another contraction of the auricles takes place, and during this pause both sets of cavities are gradually *dilating*. The contraction of the auricles and ventricles, is named their *systole*, whilst their dilatation is called their *diastole;* the order of the successive dilatation and contraction of these parts, was compared by Harvey to the successive movements of deglutition. Thus, when the auricles are dilating, they receive blood from their respective veins, and when they contract, they force the blood into the ventricles, which are then dilating to receive it; when the ventricles are filled, they in turn contract, and propel the blood into the great arteries. But the right auricle receives the blood from the body generally, and the right ventricle propels it into the lungs; whilst, of the left cavities of the heart, parted off completely from the corresponding cavities of the right side, the left auricle receives the blood from the lungs, and the left ventricle propels it into the body. As the auricles merely propel the blood into the ventricles, their walls are comparatively thin, whilst the thicker-walled ventricles have relation to the greater work they have to perform. The proportionately greater thickness of the walls of the left ventricle, and the greater strength of the mitral and aortic semilunar valves, as compared with the tricuspid and pulmonary semilunar valves on the right side of the heart, have reference to the greater force needed to distribute the blood through the body, than through the lungs.

On tracing the course of the blood, through the body and the four cavities of the heart, it is found that, proceeding from the left ventricle (Fig. 108, 8), the blood passes through the aorta and arterial system, into the capillaries of the whole body, and thence back by the systemic veins, 1, 2, into the right auricle, 3; from the right auricle it passes into the right ventricle, 4, and thence proceeds through the pulmonary arteries, 5, capillaries, and veins, 6, 6, of the lungs, into the left auricle, 7, from which it passes into the left ventricle, 8, and thence is propelled, as before, through the aorta, 9, into the arteries of the body.

The mechanism and details of these movements, are very complex. As the auricles dilate, the blood enters and distends them, that filling the right auricle, coming from the two venæ cavæ and the nutrient veins of the heart itself, that filling the left auricle, from the four pulmonary veins. As the auricles are filling, some of the blood passes through them into the corresponding ventricles, but the instant the auricles are fully distended, they contract, and discharge nearly the whole of their contents into the ventricles, which, at this period, are dilating to receive the blood. The backward flow of the blood from the auricles into the veins, is checked, more or less completely, by the contraction of the muscular fibres surrounding the orifices of the venæ cavæ and the pulmonary veins, and, as regards the right auricle, by the Eustachian and Thebesian valves, at the mouths of the inferior vena cava and cardiac sinus, and by those in the great veins at the root of the neck. The blood passes from the auricles into the ventricles, through the right and left auriculo-ventricular openings; the tricuspid and mitral valves, placed respectively at those openings, having the free borders of their segments directed towards the ventricles, offer no opposition to this movement of the blood; but the gradual filling of the ventricles, and especially their complete distension, are accompanied by a closure of the segments of the valves, the blood getting behind them, or between them and the walls of the distended ventricles. The ventricles now contract, and propel the blood into the great arterial trunks proceeding from them, *i. e.*, the right ventricle into the pulmonary artery, and through the lungs, and the left ventricle into the aorta, and through the body. The reflux of the blood towards the respective auricles, is now prevented by the sudden closure of the tricuspid and mitral valves, the segments of which are, moreover, prevented from being forced back into the auricles, by the chordæ tendineæ respectively attached to them. The blood, driven from the ventricles into the pulmonary artery and the aorta, opens the segments of the semilunar valves situated at the commencement of each of those vessels, and displaces onwards the column of blood contained within them, which, however, is not quite stationary. Four effects ensue: First, a vibratory impulse to the blood columns in the pulmonary artery and aorta, and in their branches; secondly, an increased velocity of the blood column; thirdly, an increased pressure within the arteries; and, fourthly, owing to the resistance offered by the blood in front, a distension of the elastic walls of the arteries themselves. But the ventricles, having contracted, after a short pause begin to dilate again, and then the columns of blood in the two great arteries, reacted upon by the recoil of the distended and elongated coats of those vessels, would flow back towards the ventricles, if the segments of the semilunar valves did not speedily open out across the mouths of those vessels. The blood first getting into the pouches, or sinuses, of Valsalva behind the valves, an action which is facilitated by the projecting corpora Arantii, then presses on the whole arterial surface of the segments, and so regurgitation into the ventricles is prevented. The force which thus acts upon the two columns of blood, to close the semilunar valves, is the resilience of the coats of the previously distended arteries; but it is itself derived from the heart's action, which has caused distension of the vessels. As the muscular walls of the ventricles relax, and their cavities dilate, the tricuspid and mitral valves reopen, and blood passing from the auricles, begins to fill them again. In the meantime, the auricles themselves have been dilating to the point of distension, and again, at that moment, the actions of the heart necessary to the circulation recommence, viz., the rapid contraction of the auricles, the complete distension of the ventricles, and the sudden contraction of these cavities.

A complete action of the heart consists of a single systole, and diastole of its auricles and ventricles. The period occupied in such an action commences with the systole of the auricles, includes the systole of the ventricles, and terminates at the perfect diastole of the auricles, when these cavities are fully distended and ready to perform their systole again. During this period of a complete cardiac act, the auricles contract quickly, whilst the ventricles contract a little more slowly; but the auricles dilate slowly, whilst the ventricles dilate more quickly. Hence (see the Table at p. 650), the systole and diastole of the two sets of cavities, occupy different parts of the entire period of a single cardiac action or beat.

The *diastole* of both the auricles and ventricles has been supposed to depend on an active contraction of particular sets of their muscular fibres; but it is now generally regarded as a passive phenomenon of dilatation, dependent on the rest or relaxation of all their fibres.

The *systole* of the auricles consists of a progressive contraction, which spreads from the orifices of the great veins towards the auriculo-ventricular openings, the auricular appendices acting last; the auricles, therefore, contract towards the base of the ventricles. The systole of the ventricles is not only somewhat slower, but is more uniform than that of the auricles, being simultaneous through every part of their walls, the total result being likewise to draw them towards their base, *i. e.*, towards the orifices of the great arterial trunks. By this action, the ventricular portion of the heart is shortened, rendered thicker from back to front, and more convex on its anterior surface; it is also widened a little posteriorly (Budge); at the same time, it becomes very firm and hard, like any other contracted muscular mass. Owing to the elongation of the great arterial trunks, at the moment of their distension by the blood, the base of the heart descends within the thorax; moreover, the apex is tilted upwards, and lifted a little towards the left; whilst the entire heart, owing, perhaps, to the obliquity of its muscular bands, rotates slightly on its axis, and undergoes a screw-like motion to the right. The base of the heart appears to move to a greater extent than the apex, because the downward movement of the entire heart lessens the change of position upwards, caused by the contraction of the ventricles. Some even maintain that the apex is moved a little downwards and to the left.

These changes in the form and position of the heart, bring its anterior surface a little above the apex, up to the walls of the chest, the pericardium, however, intervening, and produce a slight concussion against them. This, well known as the *impulse* of the heart, is felt most distinctly opposite a point a little below the middle of the ventricles, between the fifth and sixth ribs of the left side, 2 inches from the sternum. The impulse coincides with the systole of the ventricles.

The auriculo-ventricular valves, and the semilunar valves, are open and shut alternately at different moments of the heart's action; for the auriculo-ventricular valves are open, and the semilunar valves closed, during the diastole of the ventricles; whilst the former are shut, and the latter open, during the systole of those cavities. Their joint action is remarkable, for they determine, like the valves of the force-pump, the direction of the blood through the two sides of the heart, and hence the course of the circulation generally. The segments of the auriculo-ventricular valves, connected by the chordæ tendineæ with the sides, or with the musculi papillares of the corresponding ventricles, are first opened by the torrent of blood rushing from the auricle into the ventricle; then they are gradually raised from the sides of the ventricle, and suddenly closed, as is now generally maintained, by the action of the blood itself, during the ventricular diastole; although Haller, from observations on a living animal, believed that their closure was in part due to the action of the papillary muscles. Immediately the ventricles begin to contract, so as to change the form and size of the cavities and auriculo-ventricular orifices, and press forcibly upon the contained blood, the valve-segments, as already stated, are prevented from being driven back into the auricle by the chordæ tendineæ, which are kept *tense* by the musculi papillares contracting simultaneously with the walls of the ventricles. Were it not for the existence of the papillary muscles, the chordæ tendineæ would be relaxed, and the segments of the valves would be more or less forced into the auricular cavities. The tricuspid valve is said to close less perfectly than the mitral (Hunter); thus a certain quantity of blood is driven back into the right auricle, and also beyond it, upon the blood in the great veins, producing a slight regurgitant flow, as far as the valves of the jugular veins, and causing a *venous pulse*, synchronous with the pulse in the *carotid arteries*. The reflux thus permitted from the right ventricle is probably important, preventing the over-distension of that cavity by any temporary obstruction to the circulation through the lungs, from muscular effort or cold; it has been found experimentally, that when the heart is forcibly distended, its pulsations are immediately arrested, a condition which is thus guarded against. It is certain that the quantity of blood delivered by the right auricle into the right ventricle, is subject to variation; whilst that propelled from the left auricle into the left ventricle is probably uniform; on that side of the heart, the mitral valves close accurately, and no regurgitation takes place. Vierordt, however, doubts the normal occurrence of any reflux, even on the right side, because no such regurgitation takes place during the auricular systole, nor yet any backward pressure in the venous trunks.

The semilunar valves at the orifices of the pulmonary artery and aorta, have no chordæ tendineæ, but they meet accurately across the orifices of those vessels, the little corpora Arantii assisting in the complete closure of the three segments in the centre. These valves, opened by the blood projected from the ventricles, would be closely applied to the walls of the arteries, were it not for the presence of the pouches of Valsalva behind them; but the blood retained in those pouches, facilitates the separation of the valves from the sides of the vessels, and their subsequent opening out across those vessels, by the pressure of the blood acted upon by the distended and resilient arteries. The shock of the columns of blood in the arteries, is sustained mainly by the stronger and more tendinous part of the valves, their thinner marginal lunules being applied against each other, so as to form three lines radiating from the centre of the vessel between the contiguous borders of the valves. The greater the resilient force of the arteries, the more accurate and close is the apposition of the valves.

The closure of the auriculo-ventricular and the semilunar valves, is necessarily accompanied by a tightening out of their respective segments; this is the chief cause of certain sounds, which, on listening over the region of the heart, are heard, at stated intervals, in the period of each single cardiac beat. These *sounds of the heart* are *two* in number, in each beat. They are audible to the ear placed on the thorax; but they are commonly examined by the tubular instrument, named the *stethoscope.* In certain circumstances, they may be heard by the individual himself. The two sounds occur in quick succession, after which there is a period of silence, often named the *pause.* The *first sound* is deep, dull, and long; the *second* is higher in tone, sharp, and short. The first closely precedes the pulse at the wrist, and coincides nearly with the impulse of the heart; the second follows immediately after the pulse. Supposing the entire period of the heart's beat to be divided into eight equal parts, the first sound and the brief period which elapses between it and the second, have been said to occupy four parts; the second sound, to take rather less than two; and the silent interval, or pause, between it and the recurrence of the first sound of the next beat, to occupy rather more than two parts (Laennec); hence the period of the sounds would be to the period of silence, as 3 to 1. But the proportions have been perhaps more correctly, stated to be 2 to 1 (Williams), or nearly 1 to 1 (Volkmann).

From observations on living animals, it has been found that the first sound coincides with the systole of the ventricles, the closure of the auriculo-ventricular valves, the opening of the semilunar valves, and the entrance of the blood into the great arteries. At this period the auricles are beginning to dilate. Moreover, the first sound is speedily followed by the pulse, that in the facial artery occurring about $\frac{1}{30}$th of a second, and that in the radial artery at the wrist $\frac{1}{6}$th of a second, afterwards. The *second* sound coincides with the closure of the semilunar valves, and the opening of the auriculo-ventricular valves; whilst, at this period, the ventricles begin to dilate, and the auricles continue their already commenced diastole. The pause of silence, which succeeds to the second sound, coincides with the full dilatation, and the subsequent contraction, of the auricle, and also with the completed dilatation of the ventricles; during this pause, the semilunar valves are closed, and the auriculo-ventricular valves are open.

The *causes* of the heart's sounds have been very closely investigated, owing to the changes which they undergo in disease, and to the peculiarity of the sounds which are then developed. The *first* sound is usually referred to the closure of the auriculo-ventricular valves, either directly and solely, as being dependent on the sudden tension of their segments, or partially and indirectly, as due also to the muscular sound of the contracting ventricular walls, the sudden passage of the blood into the great arterial trunks, and the impulse of the heart itsef against the side of the chest. Unless these valves were closed, the walls of the ventricles would not act so forcibly as they do; neither would the blood rush into the great arteries, nor would the impulse of the heart be so decided. Whilst, therefore, as is commonly believed, the tension and vibration of the tissue of the closed auriculo-ventricular valves may be really the chief cause of this sound, yet the three other accessory causes, viz., the muscular sound of the ventricles, the sound of the moving blood, and its friction against the orifices of the arteries, and, lastly, the impulse of the heart against the chest, may contribute to the production of the sound as actually heard. But the importance of these causes has probably been overrated. That the muscular sound is not essential, is shown by the fact, ascertained experimentally, that the sounds are not heard, if the great veins be compressed, so that no blood enters the heart, although its contractions may continue; the production of any sound by the internal movement of the blood, or its rushing through the arterial openings, is doubtful; and ordinary muscular contraction does not give rise to any loud or sudden sound. The cause of the *second* sound appears to be better determined; it is attributed almost entirely to the tension of the suddenly closed semilunar valves, across the orifices of the aorta and pulmonary artery. The tension of the membranous substance of the valves is sufficient to cause a loud sound; but, by many authorities, the collision of the columns of blood in the great arteries, against themselves, and against the valves, so as to produce that tension, is regarded as a conjoint cause of the actual sound heard in the heart. When, in living animals, one segment of each of these valves is held back by a hooked needle, so that it cannot close, the second sound of the heart ceases. This sound has also been imitated in dead animals, by injecting fluid into the aorta, against the valves. The occurrence of changes in, and the occasional cessation of, the second sound, in cases of disease of the semilunar valves, also favor this explanation; so, likewise, does the fact that the second sound is so short, and occurs at the instant of the tightening out of these valves, and not during their subsequent and quiet closure. Lastly, there is no other simultaneous condition, or action, of any part of the heart which could produce a sound; the ventricles and auricles are, at this time, both quietly dilating, and the resilience of the great arterial trunks, forcing the blood back upon the semilunar valves, is the only mechanical action then capable of causing a sound.

The contraction of the auricles, which occurs in the latter part of the pause in the heart's beat, produces no audible sound, unless the heart be exposed, and the stethoscope be placed upon it.

It is usually held to be confirmatory of the preceding views, as to the causes of the two sounds of the heart, that the first sound is more distinctly heard opposite the fifth intercostal space of the left side, below the left nipple, *i. e.*, over the region of the apex of the ventricles, where these approach nearest to the walls of the chest, to which they communicate the sound; whilst the second sound is heard most clearly in the third left intercostal space, close to the sternum, *i. e.* over the base of the ventricles, and the commencement of the great arteries, where these approach nearest to the thoracic walls.

The difference in the pitch and character of the two sounds is partly explicable thus: the deep and dull tone of the first sound may depend on the greater size and deeper position of the auriculo-ventricular valves, on their thicker attachments, and on the quantity of muscular substance which overlies them; the higher and sharper tone of the second sound may be connected with the thinner structure and attachments, and with the less covered position of the semilunar valves.

The following Table shows the order and duration of the complicated actions of the different parts of the heart during each complete beat, and also their relations, in point of time, to the two sounds of the heart, to the subsequent pause or interval of silence, and to the occurrence of the pulse at the wrist. The duration of the events is given after Laennec.

It is seen that the first sound occupies $\frac{1}{2}$ of the entire beat, the second nearly $\frac{1}{4}$ of the beat, and the period of silence rather more than the remaining $\frac{1}{4}$. The Table likewise exhibits the alternation of the systole and diastole of the auricles and ventricles, as well as the relative duration of their respective systolic and diastolic conditions. Thus the rapid systole of the auricles, occupies only $\frac{1}{8}$th of the whole period, and their diastole $\frac{7}{8}$ths; whilst the slower systole of the ventricles occupies $\frac{1}{2}$, and their diastole the other $\frac{1}{2}$ of the whole period or beat. According to Vierordt, the period of diastole of the auricle, is really shorter, being only $\frac{2}{8}$ths or $\frac{3}{8}$ths of the whole period; the remaining $\frac{4}{8}$ths or $\frac{5}{8}$ths of that time, usually regarded as the period of diastole, must, in that case, be viewed as representing a distended, or continued dilated, condition of the auricle. In the Table, the systole of the auricles and ventricles together, is seen to occupy $\frac{5}{8}$ths, and the interval between the contraction of the ventricles and the commence-

Sounds and Movements of the Heart.

Sounds and Pause.	Duration in eighths of a Heart's beat.	Condition of Ventricles.	Condition of Auricles.	Condition of Valves. Auric.-Vent.	Condition of Valves. Semilunar.	Impulse of Heart. / Pulse.
First sound: Systolic, longer, dull, and deep,	$\frac{4}{8}$ths, ...	Contracting, . . (Systole.)	Dilating, . . (Diastole.)	Closed, . .	Open, . .	Impulse. Pulse at wrist, $\frac{1}{8}$th of a second later.
Second sound: Diastolic, shorter, sharp, and higher, . . .	rather less than $\frac{2}{8}$ths, ...	Dilating, . . (Diastole.)	Dilating or Dilated, . (Diastole.)	Open, . .	Closed.	
Period of silence,	rather more than $\frac{2}{8}$ths, — $\frac{1}{8}$	Dilating, . . (Diastole.)	Dilated, . . (Diastole.)	Open, . .	Closed.	
	$\frac{1}{8}$	Dilated, . . (Diastole.)	Contracting . (Systole.)	Closing, .	Closed.	

ment of the next beat, $\frac{3}{8}$ths of the whole period. According to Cheveau, however, the ventricular systole in the horse occupies only a little more than $\frac{1}{5}$th of the entire beat; Sanderson's researches coincide with this statement as to the great rapidity of that event.

At each beat of the heart, the ventricles are supposed to be almost completely, if not entirely, emptied; the left ventricle is often found in that state after death, especially if examined during the period of the rigor mortis. On a section, the walls of that ventricle are then seen to be so thick, from their contraction, as to have been frequently described as being hypertrophied. Although the right ventricle, as already mentioned, allows a little blood to escape back into its corresponding auricle, yet both ventricles are supposed to throw practically, equal quantities of blood; for, unless this were so, the left ventricle would receive either too little or too much blood from the synchronous action of the right ventricle, the quantity of water lost, as vapor, from blood, in its course from one ventricle to the other, through the lungs, being insignificant, amounting to less than $\frac{1}{6}$th of a grain, during each beat of the heart. The quantity of blood thrown at each systole, by the ventricles, was formerly said to be, in the adult, about 4 oz., which was described as the normal capacity of each of those cavities; but the most recent researches have led to higher estimates, viz., 5.3 oz. (Valentin), 6.2 oz. (Volkmann), and even 6.3 oz. (Vierordt). Positive measurements are impossible; the results obtained rest on various calculations in hæmadynamics, to be hereafter mentioned. The capacity of the auricles is said to be rather less than that of the ventricles, but the quantity of blood which they contain is sufficient to distend the ventricles, as these are partly filled by blood flowing through the auricles into them, before the occurrence of the auricular systole.

The *force* of the *auricular contractions* cannot be measured. From observations on the blood-pressure in the *arteries*, the force of the *left ventricle* is estimated to be equal to about $\frac{1}{50}$th part of the weight of the entire body; whilst that of the *right* ventricle, is supposed to be less than half that force. The difference in the average thickness of the walls of the two ventricles, which is about as 3 to 1, affords one ground for estimating the difference in their power.

The dilatation of all the cavities of the heart is, at least chiefly, an intrinsic or spontaneous act, and not simply a passive distension, caused by the blood flowing from the veins into the auricles, or by that forced by the auricles into the ventricles; for when the heart of an animal is removed from the body, or even when its auricles are separated from the ventricles, both sets of cavities not only contract, but dilate. In neither of these conditions, however, does any internal pressure, or dilating force, act upon their interior, like the blood in the living state; the cavities of the heart must therefore dilate spontaneously, owing, as already mentioned, to the relaxation of their previously contracted muscular walls. This dilatation assists the entrance of blood into them, by diminishing the resistance to the passage of that fluid; it thus saves the waste which would occur in the employment of a special dilating force.

The heart in Man, as observed in the case of beheaded criminals, beats only a few minutes after their execution; this is also true of the warm-blooded animals. Its contractions continue much longer, after systemic death, in cold-blooded and hibernating creatures. The actions of the heart become slower and irregular, ceasing last in the right auricle, the so-called *ultimum moriens*. They are stimulated by heat, the injection of fresh blood, the action of oxygen, and by galvanism; they are arrested by carbonic acid, sulphuretted hydrogen, the vapor of chloroform, and also, after a time, in a complete vacuum.

The beats of the heart, recurring at more or less regular intervals, exhibit an example of so-called *rhythmic* action; their rhythm, like that of the respiratory movements, is, indeed, very remarkable. The cause of this rhythm was, at one time, supposed to be the stimulation of the inner surface of the cavities of the heart by the blood, and it was further imagined that some relation might exist between the special irritability of the right side of the heart, and the qualities of the dark or venous blood returning from the body, and also between that of the left side of the heart, and the qualities of the red or arterial blood entering them from the lungs. Moreover, the ventricles, stimulated to contract by their contents, were supposed, after forcing the blood through the body and lungs respectively, to accomplish the filling of the auricles; the contraction of these, excited in a similar manner by their contents, was supposed once more to fill the ventricles, and so on. The muscular walls of the heart undoubtedly possess great irritability even in a warm-blooded animal; the inner surface of the auricles and ventricles is also both sensitive and excitable, and is certainly more rapidly acted on by poisons than their outer surface. (Henry.) But the heart, or even a separate portion of that organ, taken from a hibernating warm-blooded, or from any cold-blooded Vertebrate animal, may not only retain its general irritability for days, but may continue, for a time, to perform *rhythmic* contractions and dilatations, even if removed from the body, though no blood is left in it, and though freed from the stimulus of oxygen, as when placed in a vacuum. The frog's heart will beat thus for twelve hours. Although, therefore, the rhythmic motions of the heart in the living animal may be partly due to the stimulus of the blood entering its cavities, yet this cannot, under all circumstances, be the cause of such rhythmic actions.

Through the pneumogastric nerves, the *cerebro-spinal* nervous centres, as shown by experiment and by observation in disease, greatly influence the heart's action, under some circumstances increasing, and under others, lowering or inhibiting it (p. 307); but there is no evidence of their being the cause of the rhythmic character of its movements. The action of the heart is influenced by the emotions and passions, and, according to some, even by the will. In the celebrated case of Colonel Townsend, recorded by Cheyne, the breath could be held, and thus the movements of the heart could be controlled by an act of the will. The heart is excited or depressed by various diseases of the brain, as by cerebral inflammation on the one hand, and by apoplexy on the other; and its action is disturbed, or even abruptly suspended, by severe injury or destruction of the brain or spinal cord, or of these two parts of the nervous centres together. These and other phenomena of a similar kind are due to excitement or shock, and their effects are often more or less transitory. The *sympathetic* nervous centres, and the cervical parts of the spinal cord with which they are connected, also influence the movements of the heart, as is shown by experiments, and by the effects of blows on the abdomen, or of other injury or disease (p. 307). But if the injury, either to the cerebro-spinal or sympathetic system, be gradually inflicted, the heart's movements will continue, even although the brain and spinal cord be removed, particularly if artificial respiration be performed. From these facts, and especially from the circumstance that the rhythmic movements continue after the removal of the heart, it is evident that the regulating agent of these movements is not in the great nervous centres, but somewhere in or upon the heart itself. It is now admitted, indeed, that the numerous sympathetic ganglia connected with the nerves upon the heart, are the sources of the stimulus or force which excites the rhythmic contractions of its muscular fibres. In the hearts of the frog and tortoise, these ganglia are chiefly found near the junction of the auricles and ventricles, in the neighborhood of the auriculo-ventricular openings. If the heart of one of these animals be removed from the body, and be divided *longitudinally* into its right and left halves, the auricle and ventricle in each half will still continue to contract and dilate rhythmically; if, however, the heart be divided *transversely*, below the base of the ventricles, so that a larger or smaller portion of the ventricles is detached from the rest of the heart, the auricles and the base of the ventricles which are connected, continue to contract rhythmically. But the separated piece of the ventricles no longer does so, although isolated and spreading contractions may still be excited in it, by the application of a mechanical or other stimulus. By yet further sections, the regulating agent of the rhythmic action is shown to be confined to the immediate neighborhood of the auriculo-ventricular orifices, or to the line of junction between the auricles and ventricles, in which part the chief ganglia are found. The synchronous combination of the auricular and ventricular motions on the two sides, may be due to connections between the several ganglia. These local cardiac ganglia must be regarded as nervous centres, which originate a co-ordinate and rhythmically exerted energy, stimulating the muscular fibres of the auricles and ventricles to perform their characteristic movements, in regular and periodic succession. It has been suggested that these nervous centres exert or discharge such energy rhythmically, or at periodic intervals, owing to a periodicity in their nutritive processes, by which they alternately accumulate and discharge the nerve-force necessary to excite the muscular substance of the heart. (Paget.) Why this periodicity of nutrition occurs, is still unexplained.

It has been supposed that the condition of the blood distributed to the substance of the heart itself may, in some way, determine its rhythmic actions, either the presence of dark venous blood in its capillaries directly stimulating the muscular contractility (Brown-Séquard), or the absence of oxygen acting in a similar manner. (Radcliffe.)

When the heart of a cold-blooded animal is removed, irritation of any part of it is propagated to the rest, and rhythmic contractions are set up; but if the heart be partially divided, the effects of the irritation may be still conducted along muscular parts, but not along the tendinous structures. In the entire heart, when removed, the auricular contractions always begin at the sinus; this fact, and also the successive actions of the auricles and ventricles, justify the comparison of these movements to the progressive peristaltic motions of the œsophagus and intestines. When a ligature is applied around the entrance of the venæ cavæ into the right auricle, the auricles and ventricles remain for a time distended, but the sinus continues to contract.

The *frequency* of the beats of the heart, as indicated by the impulse against the left side, and by the pulse, averages, in a healthy adult, about 70 in a minute; but in the male, it is below, and in the female, above that number. The frequency of the heart's beats, and therefore of the pulse, is modified, however, by many circumstances. It is affected by the stature, being slower in tall, and quicker in short persons. The influence of sex just indicated may possibly be due to the accompanying difference in stature; the difference in the sexes ranges from 10 to 14 per minute. Age has a still more remarkable effect. Thus the pulse is quicker before birth than after. In infancy it is very rapid, and it gradually diminishes in frequency as life advances. It is said, however, to be somewhat slower in infants under six months of age, than after that period, and also to become quicker again in extreme old age:

Frequency of the Pulse at Different Periods of Life.

Periods of Life.	No. of Beats per Minute.
Before birth,	150
At birth,	140 to 130
First year,	130 " 115
Second "	115 " 100
Third "	100 " 90
Seventh "	90 " 85
Fourteenth "	85 " 80
Adult life,	75 " 65
Old age (above 70),	80 " 75

Temperament and idiosyncrasy modify the number of the heart's beats, which are fewer in phlegmatic, and quicker in sanguine and nervous persons. The heart beats more slowly in sleep, and more quickly during excited states of the mind or body; the depressing passions lower the number of its beats, or even arrest its movements altogether. Disease sometimes, as in fever and inflammation, increases the frequency of the heart's action, or, as in compression of the brain and in apoplexy, diminishes it. Loss of blood, when gradual and moderate, diminishes the frequency of the heart's beats; whilst sudden or excessive hemorrhage increases them. The effect of taking food, is to accelerate the heart's action, animal food producing a more immediate effect, and vegetable food a more lasting one: warm food acts more quickly than cold. The effect of alcoholic and other stimulants is well known, and is indicated by their title. It is alleged that the pulse is more accelerated after breakfast than after dinner. Abstinence and starvation lower its frequency, so also does the prolonged use of a vegetable diet, or the drinking copiously of water. Muscular exertion increases the number of the heart's beats, an alternate contraction and relaxation of the muscles, having a greater effect than a continuous contraction; it also increases the respiration. Posture has a remarkable influence, evidently dependent on the muscular effort expended in maintaining different positions of the body; thus, the beats of the heart are slowest in the recumbent, somewhat quicker in the sitting, and most frequent in the standing, posture. The increase per minute, produced by the change from the recumbent to the sitting position, is 6, and from the latter to the standing posture 9 more, *i. e.* a difference of 15 occurs between the lying and standing positions. The effect of posture is greater in the morning than in the evening, and it is greater also when the pulse is quick than when it is slow, the difference resulting from the change between lying down and standing being 9 only, when the pulse is 60, 15 when the pulse is 80, and 27 when the pulse is already 100 (Guy). That the increase in the heart's beats, from change of posture, is due to muscular effort, is shown by placing a person in the recumbent position on three chairs, and then removing the central one, when the pulse immediately rises, although the horizontal position is still maintained; whereas, in a person fastened to a revolving board, and moved into the erect posture, without effort of his own, no such elevation of the pulse takes place. The frequency of the heart's action undergoes changes coincident with the seasons, being greater in spring and summer than in autumn or winter. The rapidity of the heart's action is also influenced by the hour of the day, being always quicker in the morning, and somewhat retarded towards evening, other conditions as to health, food, and the state of the body being equal; this difference depends, doubtless, on the gradual exhaustion of the powers of the system during the day's work, and on the recovery of power by the rest obtained at night; it may partly explain, why the pulse is more accelerated after breakfast than after dinner. During fasting, the pulse exhibits three periods of increased rapidity, and three periods of descent in the twenty-four hours; thus, it rises from midnight to 2 A.M., from 10 to 11 A.M., and from 2 to 6 P.M.; whilst it falls from 3 to 4 A.M., from 1 to 2 P.M., and from 6 to 8 P.M. The joint effect of the time of day and of food, is illustrated by the fact that the pulse, though progressively decreasing from two hours after breakfast to from 3 to 5 in the morning, exhibits fluctuations after each meal, so that four maximum, and four minimum, points are noticeable daily. The difference between the highest and lowest points, varies from fourteen to thirty-four pulsations. The minimum points are all observed before meals, the maximum points about two hours afterwards, the greatest increase being after breakfast. External temperature and its concomitant effects on the body, also influence the beats of the heart most materially, an elevation of temperature increasing, and a gradual lowering of the temperature diminishing, their frequency, as is illustrated by the exciting effect of a warm bath, and by the influence of long-continued exposure to cold; but the sudden and brief application of cold, accelerates the beats of the heart. Elevation above the level of the sea—in other words, a diminution of the atmospheric pressure—is found to increase the beats of the heart; thus, Dr. Frankland, whose natural pulse is 60, found that after six hours' sleep on the summit of Mount Blanc, thus excluding the effects of recent muscular effort, his pulse was 120 per minute; on reaching, in the descent, the so-called Corridor, it was 108; at the Grand Mulet it was 88; and at Chamounix it was 56. As one effect of high elevation is to increase the frequency of the respiration, in consequence of the greater tenuity of the atmosphere, and, as a relation exists between the frequency of the heart's action and the respiratory movements, the increased rapidity of the pulse in elevated positions may thus be partly explained. An increase in the density of the atmosphere, such as takes place in a submerged diving-bell, is said to lower the frequency of the pulse, and also the movements of respiration. An increase of barometric pressure of $\frac{1}{5}$th of the normal pressure, lowers the pulse, on an average, ten beats per minute, whilst the respirations are simultaneously lessened by two. (Vivenot.)

The normal relation between the number of respirations and the heart's beats is, on an average, 1 to 4; in diseased conditions, this ratio is often interfered with, but it is preserved in those accelerations or retardations of the breath and pulse, which take place in the healthy state, such as those due to exercise, change of posture, food, stimulants, and emotion, or to the opposite conditions of rest, abstinence, or depressing influences. Thus, if the normal respirations were 16 per minute, the pulse would be about 64; and if the former were increased to 18 or 20, the latter would be raised to 72 or 80. Expiration diminishes, and inspiration increases, the frequency of the pulse.

A certain relation appears to exist between the facility or the difficulty of the capillary circulation, and the rapidity or slowness of the heart's action; and this may explain some of the preceding phenomena. Thus, the application of cold to the surface of the skin, limiting or checking the circulation through the systemic capillaries, by contracting the small arteries, is accompanied by a retardation of the heart's beats; a state of repose acts, but less powerfully, in the same way. A feeble and slow respiration, lessening the capillary circulation through the lungs, has a similar effect; so also has holding the breath. On the other hand, exercise and heat quicken the systemic capillary circulation, and also increase the frequency of the ventricular systoles, and so does a quickened and active condition of the respiration. Any obstacle to the flow of blood through the vessels, and thereby to the action of the ventricles, appears therefore to be sympathized with, and a reduction of the heart's beats is the result; whilst the removal of such obstacles is followed, in like manner, by the greater rapidity of the beats. Exercise, excitement, and food, probably, also act on the heart, by producing a greater flow of blood to that organ.

Not only the frequency, but the *force* of the heart's beats, may be modified by external or internal circumstances. This force is increased by all those conditions which may be characterized as stimulating or strengthening, such as exercise, food, stimulants, repose, and so on; whilst depressing and weakening conditions, on the other hand, lessen its force. Stimulating medicines, such as ammonia, ether, or alcoholic preparations, increase the force and frequency of the heart's beats; whilst sedatives, and especially digitalis, diminish their frequency, the latter drug not lessening the force. The *impulse* of the heart, generally proportional to the strength of the body, is affected by various conditions; it is least felt in the recumbent position, on the back or on the right side, and most distinctly in the prone position, or when lying on the left side; in the upright posture it is moderately strong. The impulse of the heart is less manifest in stout persons, but much more evident in thin ones; it is also more perceptible during a forcible expiration, and less so during a powerful inspiration, because, in the latter case, the heart is overlapped by the inflated lung, whilst in the former, it approximates closely to the walls of the chest. It is also increased by exciting causes, such as exercise, food, stimulants, and certain emotions which produce the so-called perceptible impulses constituting *palpitation of the heart.* As already mentioned, the rhythm of the heart may be interfered with by causes acting through the nervous system, in which case it may even become irregular, so that successive beats of the heart take place at unequal intervals of time, or certain beats may altogether intermit.

Lastly, the force, rhythm, impulse, and likewise the sounds of the heart, are variously modified by morbid conditions of that organ and the adjacent parts, as by thickening or hypertrophy, thinning or atrophy, of its walls, thickening and imperfect closure of, or irregular growths on its valves, adhesion of the pericardium to the heart, or the presence of membranous deposits or fluid between it and that organ. The impulse and sounds may even be altered by affections of the lungs, pleura, or thoracic walls. The morbid changes in the sounds of the heart, are distinguished by terms descriptive of their character, position, cause, or period of occurrence. Thus, there are murmurs blowing or rasping, and friction-sounds; mitral or tricuspid sounds; aortic or pulmonary; regurgitant or constrictive; diastolic or systolic. The most marked and frequent murmurs are the mitral regurgitant, from imperfect closure of the mitral valve, and the aortic constrictive, from narrowing of the orifice of the aorta. General enlargement of the heart increases the area of local dulness on percussion of the chest, due to the contrast between the solid heart and the inflated lung. Fluid effused into the pericardium, also increases the dulness; but, moreover, it weakens or gives a distant character to the heart's sounds. Drier and solid effusions, as of lymph, cause a peculiar pericardial friction-sound, or even tremors, which may be felt in the thoracic parietes, dependent on a rubbing together of the surfaces of the heart and its pericardial sac.

Motion of the Blood through the Arteries, and Influence of those Vessels on the Circulation.

The phenomena of the circulation of the blood through the arteries, have been studied exclusively in the systemic arterial vessels; for the pulmonary arteries and their branches are removed from direct observation and experiment. The structure and distribution of the arteries, the properties of their coats, and their mode of subdivision and anastomoses, already described (pp. 25 and 54), have important influences on the motion of the blood through them. The very smooth, glassy surface of the internal coat serves, like that of the endocardium of the heart, to diminish the friction between the blood and the sides of the bloodvessels.

The remarkable physical property of *elasticity*, possessed by the middle arterial coat, is of extreme importance; it exists in a more striking degree in the larger arteries, especially in those near to the heart; it is manifested not only on stretching the vessel in a lateral, but also in a longitudinal direction. Two purposes are served by this elasticity; first, it protects the arteries against the force of the heart, to which they yield, instead of offering a rigid resistance; and, secondly, it enables them to recoil, after they have thus yielded, and to react upon the column of blood within them. It is this recoil which gradually converts the intermittent force of the heart into a continuous pressure in the small vessels. Moreover, the elasticity of the arteries enables them to bear occasional increase in the quantity of blood forced into them from the ventricles, as in conditions of excitement; or a more permanent addition to the normal quantity, as in plethora. Lastly, it prevents their compression by the ordinary muscular movements, and permits them to bend and elongate, and so to accommodate themselves to changes of position in the trunk and limbs.

The *vital contractility* of the involuntary muscular arterial walls, is of equal importance. Contrary to what is the case with their elasticity, this contractility is feebly manifested by the larger arteries, but is very active in the smaller ones. This property of the arteries is shown by their slow contraction after death, owing to which, when no longer distended by the force of the heart, they contract, and are usually emptied of blood; also by their contraction under the influence of cold, heat, and mechanical, chemical and electrical stimuli, applied either to themselves, or to their nerves. Like the contractility of the other muscular fibres of organic life, that of the arteries is slow in its manifestation. Different stimuli, however, act differently in exciting it. Some are said to cause slow contraction, and others a more rapid contraction, with subsequent slow return to the natural state; some speedily produce marked dilatation, and others, a dilatation, followed slowly by a persistent condition of contraction. The stronger the stimulus, the more likely is it to produce this latter effect. The tonic contraction of an artery is powerfully excited by cold; whilst warmth relaxes it; but a caustic heat causes the most durable contraction, which may, in part, explain the effect of the actual cautery in arresting hemorrhage. John

Hunter demonstrated the existence of this contractility in portions of the moderate-sized arteries, which, he showed, went on contracting, for a time, after death, by a sort of *rigor mortis*, and then dilated again, owing to the resiliency of the elastic coat. Poiseuille found that, after subjection to an equal distending force, an artery, which still retained its vital contractility, contracted more than a perfectly dead one; he also observed that when a living artery was injected with a certain force, it recoiled with a *greater* force, a result implying more than the reaction of mere elasticity, which could only be equal to the original force. The vital contractility of the smaller arteries, has been demonstrated in the mesenteric arteries of toads and frogs, by means of cold (Schwann), by the application of magneto-electricity to the frog's web (Weber and Kölliker), and in still smaller vessels in the mouse, bat, and frog, by various chemical, irritant, and mechanical stimuli (Wharton Jones, Lister, and many others). Weber found that minute arteries begin to contract in two or three seconds after stimulation; in five to ten seconds, they are diminished to half their original area, and, the stimulus being continued, become completely closed, after which, the electrical current being removed, they slowly dilate again to their original size. The vital contractility of the arteries may be excited through the nervous system, either directly, or in a reflex manner; for they undergo changes in diameter, through the contraction or relaxation of their muscular coat, induced by division or irritation of the vasi-motor nerves or nervous centres (p. 308). Two purposes are fulfilled by this vital contractility of the arteries; first, that of slowly adapting the capacity of the entire arterial system, to the quantity of blood circulating through it; and secondly, under the control of the nervous system, that of modifying the relative quantity permitted to flow to any given organ. Moreover, if, during life, a small artery be cut quite across, its contractility closes its orifice, and so arrests further hemorrhage. This fact, indeed, is quoted as a proof of its contractility; for the elasticity of the arterial walls is insufficient to account for the perfect contraction of a wounded vessel, and would rather tend to keep it partly open, as we see happens in a dead artery.

It has been supposed that the contractility of the arteries might serve, as well as their elasticity, to adapt them to the intermittent and variable pressure of the blood projected into them by the heart; but there is no evidence of this, and the characteristic slowness of action of organic muscular fibres, renders it doubtful whether the arteries could alternately relax and contract, concurrently with the rapid action of the heart.

The so-called *tone* of the arterial system, seems to depend on a healthy contraction of the muscular coat—the so-called property of *tonicity* being a continued exercise of muscular contractility. This tonicity is shown by the contraction which takes place in the portion of an artery included between two ligatures, when it is punctured to allow of the escape of its contained blood; also by the gradual emptying of an arterial trunk beyond any point at which it has been tied—a contraction much more complete than elasticity can explain; and, again, by the almost complete obliteration of the canal of a portion of artery removed from a living animal, and subjected to continued cold. The elasticity of the artery is, however, also, incessantly at play in the natural state of the vessel, which is always in a condition of moderate and constant tension, permitting and explaining its slight contraction and retraction into its sheath, when it is divided.

As already stated, by the successive contractions of the ventricles, and by the closure of the auriculo-ventricular valves, the blood is not only directed from the heart into the great arterial trunks, but is also projected into them by successive jerks. If the arteries had rigid inelastic walls, this intermittent motion of the blood in them, would be propagated even to the capillary system. Owing, however, to their elasticity, and to the successive closure of the semilunar valves across the mouths of those vessels, the separate impulses caused by the ventricular contractions, are gradually rendered less distinct, and, finally, before the stream of blood enters the capillary vessels, its motion becomes continuous. The elastic coats of the aorta, near the heart, having been distended by the force of the left ventricle, recoil on the contained blood; this fluid being practically incompressible, transmits the pressure on itself, *backwards*, so as to close the semilunar valves, and *forwards*, so as also to urge onward the column of blood in the systemic arteries. But the intermittent effect of the heart's strokes, is propagated onwards through all the main arteries of the body, in which it is manifested by the pulse, and by the escape of the blood per saltum, or in jets from any of those vessels when they are wounded. The motion of the blood from the ventricle is truly intermittent—that is, it ceases absolutely at intervals; the jet from a large artery, when wounded, is not quite intermittent; that from the smaller arteries, though the stream is jerking, is distinctly *remittent*, *i. e.*, the jet never ceases altogether, but is alternately stronger and weaker; finally, in the smallest or microscopic arteries, the flow of the blood, under ordinary circumstances, loses even the remittent character, and becomes perfectly equable and continuous, and remains so in the capillary vessels. This effect of the elastic recoil of the previously distended arterial walls, may be illustrated by the action of a vulcanized india-rubber tube, which, if of sufficient length, changes the jerking flow of water, forced into it by a syringe or pump, into a flowing stream. The force of the ventricle, transmitted through the column of blood, acts most powerfully on the vessels nearest to the heart, in which the elastic tissue is most abundant; whilst the effect of the ventricular force is gradually weakened in the more distant vessels, the elastic coat of which becomes proportionally thinner. On the contrary, as already mentioned, the muscular fibres are relatively least abundant in the largest, and most so in the smallest arteries; and it is improbable that their contractility is called into play, to resist the distending effect of the heart's force. Although the arteries, by their resilience, at length convert the intermittent stroke of the heart into a uniform propulsive force, yet the heart itself is still the moving agent of the arterial blood; for the recoiling force exercised by the arteries, is itself due to their previous distension by the force exerted by the heart. When, indeed, this force is too weak to distend the arteries as usual, the remittent flow, or jerking escape of the blood, is observed in the most remote arteries, not only in those next to the capillary vessels, but even in the capillaries themselves. The elasticity of the arteries engenders no new force in the circulation, but utilizes that of the heart. Without it, the force of this organ would probably rupture the microscopic arteries, or the capillaries of many delicate structures, and so give rise to internal hemorrhages or apoplexies; such accidents, indeed, occur when the coats of the arteries are converted, by disease or degeneration, into more or less rigid tubes. Besides acting in the distension of the coats of the arteries, a certain part of the heart's force is lost, being propagated, by disturbance of those vessels, to the neighboring hard or soft tissues.

The frequent branchings and bendings, and especially the anastomoses of the arteries, or their communications with one another, as they approach the organs to which they are distributed, as well as in the interior of those organs, serve to diminish, as well as to equalize, the force of the heart's action. The multiplication of the smallest arteries, and, therefore, of their points of entrance into certain delicate organs, as seen in the ciliary arteries of the eyeball, and in the pia-mater of the brain, must also lessen the pressure upon each of them. Moreover, the frequent anastomoses of the arteries, as in the vicinity of the joints in the limbs, and especially at the base of the brain, serve to secure a due and constant supply of blood to a given part through certain vessels, when others are temporarily obstructed by external or internal pressure, or permanently interrupted by aneurisms, tumors, or accidental division of the ligature of an arterial trunk. Anastomosing branches given off above and below the seat of ligature, gradually, or even rapidly, enlarge, forming large collateral vessels, through which the so-called *collateral circulation* is carried on. Such enlargement of an artery is due, not to a mere relaxation of its coats, and consequent dilatation, but to an increased nutrition of its walls, by which it undergoes a positive enlargement; in like manner, arteries which are no longer traversed by blood, though, in the first instance, they merely contract, afterwards become reduced in size, by a positive atrophy or absorption of their coats.

The *supply* of blood to a given organ, depends primarily upon the size of the main artery distributed to it; but secondarily also, upon the rate of motion of the blood through those vessels, which varies, as we shall see, according to many circumstances. But, as previously mentioned, the calibre of the arteries, especially of the smaller ones, is not constant; for it undergoes changes in accordance with the state of relaxation or contraction of their muscular coat, being sometimes of normal size, and sometimes larger or smaller than usual. The increased redness of the cheeks in blushing, or that of irritated and inflamed parts, depends partly upon a temporary change in the calibre of the smallest arteries, which are then manifestly dilated. Hence the supply of blood to a part or organ, may also be regulated by the contractility of its arteries, which is itself controlled by the nervous system.

The *rate of motion* of the blood in the arteries has been calculated from observations made upon animals. Two kinds of instruments have been employed in such observations. One, the *hæmadromometer* of Volkmann, consists of a bent U-shaped glass tube, having its ends fitted into a short, straight, hollow metallic mounting, placed at right angles to it. By means of stopcocks, a free passage can be maintained, either through the straight portion of the apparatus only, or through the bent U-shaped part. When the two ends of the straight portion of this instrument are fastened into the cut ends of the divided carotid artery of a dog, the arterial blood-current may either be allowed to flow through the straight portion, or it may be suddenly diverted, by changes in the stopcocks, through the bent or U-shaped part. The rate of motion of the blood through the latter, being observed, and the length of this tube being known, the velocity of the blood-current is ascertained. Another instrument, the *hæmatochometer* of Vierordt, is composed of a small square box or cell, made with glass sides, filled with water, and having an aperture of entrance and one of exit, each fitted with a tube; to these tubes, the cut ends of a divided artery are attached. Within the box is a fine pendulum, carrying, in order to aid the observation of its movements, a disc of silver, which, when the pendulum is at rest, hangs close to the aperture of entrance. A curved graduated scale is marked on the side of the vessel. When the arterial blood is permitted to flow into this box, it raises the pendulum with a velocity corresponding with that of its own motion, and which is at once measured by the graduated scale. According to Vierordt, the mean velocity of the blood in the carotid of a horse is 11.7 inches, of the dog 10 inches, and of the calf 9 inches per second; the calculated velocity in the aorta of the horse is 12.5 inches, and in the human carotid, rather more than 10 inches per second. According to Volkmann, the velocities for the carotid artery in these animals, are a little higher; but in the metatarsal artery of the horse, only 2.2 inches per second. By means of the *tachometer* of Chauveau, a modification of Vierordt's instrument, it is shown that a great difference in the velocity of the blood-current, exists during the systole and diastole of the left ventricle; for during the systole, in the horse, the velocity is about $20\frac{1}{4}$ inches, and during the diastole only $8\frac{3}{4}$ inches per second. The velocity of the blood in the arteries is, moreover, diminished during inspiration, and increased during expiration.

From the preceding figures, it appears that the rate of motion of the blood in the arteries is quickest near the heart, gradually becoming slower in the more distant vessels. First, the effect of the heart's action is diminished by the resistance offered, by friction and adhesion, to the passage of the blood through the arteries and capillary vessels; this frictional resistance, though rendered as slight as possible by the smooth lining membrane of the arteries, is increased by the curvature, by the angular bending, and by the frequent subdivision, of the arteries, by an unusual rigidity of the walls of the arteries, and by any alteration in the viscidity of the blood, or in its nutritive attractions for, or relations with, the capillary walls and the tissues beyond them. All these conditions, therefore, tend to retard the velocity of the blood-current, by an increase of resistance and friction.

Secondly, the force of the heart, and therefore, the rate of motion of the blood, is wasted by the slight loss from friction between the particles of the elastic coat of the vessels, occurring in their distension and recoil, and likewise by the disturbance of the artery and the surrounding tissues. Lastly, an efficient cause of retardation in the arterial blood-current, is the obvious increase in the total capacity of the branches of the arteries, as compared with that of the trunks from which they arise; for not only do the united *diameters* of two or more branches exceed the diameter of the parent trunk, but, though of course in a much less degree, the combined *areas* of two or more branches, are usually larger than the area of the parent trunk. The combined areas of the two iliac arteries, into which the abdominal aorta divides, are, however, larger than that of the aorta itself. Opening an artery, which not only causes hemorrhage, but also diminishes the resistance in the arteries, increases the velocity of the blood in the opened vessel: this result may be exhibited by experiments with artificial tubes injected with water, and then opened.

The *force* of the heart, or the blood pressure, in the arteries, has been frequently investigated, both by the earlier and later physiologists. Stephen Hales found that, on fitting a long tube containing water, into the crural artery of horses, the force of the blood-current was sufficient to elevate the water in the tube, to heights varying, in different cases, from 8 feet 3 inches to 9 feet 8 inches. From these and other experiments, he inferred that the pressure of the blood in the large arteries of the human body, would support a column of blood 90 inches, or 7 feet 6 inches high, or a weight of 3 pounds 7 ounces per square inch. More recently, Poiseuille invented the *hæmadynamometer*, a much more convenient instrument, in which a short column of mercury is substituted for the longer column of water in Hales's apparatus. This instrument, as now improved, and named a *manometer*, consists of a U-shaped glass tube, having one of its stems or legs longer than the other; the shorter leg is bent horizontally, and provided at its end with a stopcock, and with a piece of elastic tube, so that it can readily be adapted to the cut end of a divided artery in a living animal. The lower curved part, and 3 or 4 inches of both legs of the U-shaped tube, are filled with mercury, and the space in the short leg, between the surface of the mercury and the stopcock against which the artery is fixed, is occupied with a solution of common salt, sulphate of soda or Glauber's salt, or carbonate of soda, so as to prevent the coagulation of the blood when it enters the apparatus. At the back of the tube is fixed a graduated scale, the zero of which corresponds with the level of the mercury when at rest in both legs. When the horizontal part of the short leg of this instrument is connected with an artery, and the stopcock is opened, the apparatus being maintained in a vertical position, the force of the blood-current depresses the mercury in the shorter, and raises it in the longer leg. The difference between the level of the mercury in the two legs, gives the height of the mercurial column supported by the blood pressure. But the level of the mercurial column in the longer leg is very inconstant; for it is raised at each ventricular systole, and lowered at each diastole: the highest point indicates the full power of the heart, overcoming the resistance of the column of blood, and distending the arterial walls; whilst the lowest point shows that force, reacting through the resilience of the arteries only. The mean height between the two levels, is usually recorded as the average blood pressure. Hales had already noticed, in his apparatus, a descent of 1 inch in the blood column, between each pulsation. To determine the exact force in pounds weight, the difference between the sectional area of the artery experimented upon, and that of the tube containing the mercury, must be noted and the weight of a mercurial column of the indicated height, but of the same area as the artery, must be determined by calculation. Should any blood descend into the tube, its weight must be reckoned, though it is only $\frac{1}{10}$th the weight of mercury.

By means of a simple hæmadynamometer, Poiseuille found that the blood pressure varied little in different sized arteries, and in different sized animals; and he concluded that 6.3 inches of mercury was, in all cases, the average equivalent of pressure. This general result corresponds nearly with that calculated by Hales for Man; thus mercury being 13.6 times heavier than water, 6.3 inches of the former would be equal to 85.68 inches of the latter, Hales's estimate giving 90 inches of blood, which are equal to 95 of water. Again, 6.3 inches of mercury on the square inch would be equal to 3 lb. 2 oz. pressure, Hales's estimate being equal to 3 lb. 7 oz.

The force of the left ventricle itself can only be estimated from that observed in the arteries nearest to the heart; taking the blood pressure in the aorta at 6.3 inches of mercury, then the force of the left ventricle is found by multiplying that number by the square inches contained on the internal surface of that cavity.

The uniformity of pressure believed by Poiseuille to exist in arteries, both near to and distant from the heart, which was thought to equalize the force of the circulation in every part, and so to render congestion or deficiency of blood ordinarily impossible, does not appear to prevail. In a system of rigid tubes, the pressure would be uniform, unless these were of very great length, and then only from friction. In curved and resilient tubes, however, branching into vessels of rather larger area than the trunks, some loss of force must be sustained. Neither is it true, as Poiseuille supposed, that, in a series of animals of different size, the blood pressure in the arteries is nearly uniform, because, as he alleged, it is regulated by a relation between the force of the ventricle, and the size of the aortic orifice.

An adaptation of the hæmadynamometer, named the *kymographion*, which yields very accurate results, has enabled more recent experimenters to correct the observations and conclusions of Poiseuille. Upon the surface of the mercury in the longer leg of the ordinary instrument, there rests a float, which is made to carry a vertical rod; on the upper end of this is fixed a horizontal pencil, having its point resting on a drum capable of revolving upon a vertical axis. When the instrument is in use, the drum is made to turn at a given rate, by clockwork, and the pencil, moved by the mercury, describes a waved line corresponding with the variations in the blood pressure. In this way, the pressure is shown by Ludwig, Volkmann, and others, to vary in animals of different size, and, in the same animal, in arteries at different distances from the heart, as well as according to different states of the circulation, respiration, and nervous system. Thus, in the horse the average blood pressure was nearly 11 inches; in the dog, nearly 6 inches; in the rabbit, as a mean, rather more than 1 inch; and in the frog, rather less than 1 inch. Again, in the carotid of the calf, the pressure was equal to $4\frac{1}{2}$ inches of mercury; but in the metatarsal artery to only $3\frac{1}{2}$ inches. Lastly, in medium-sized animals, the blood pressure varies from $\frac{1}{5}$th to $\frac{2}{5}$ths of an inch in the larger vessels. According to other authorities, it differs much more than this, even in the same artery. Moreover, there are slight fluctuations, due to the state of the respiration, to hemorrhage, starvation, muscular effort, and other causes, implying variations in the force of the heart, either increase or diminution. The pressure is weaker in younger animals. In the pulmonary arteries, the pressure is only equal to from $\frac{1}{2}$ to 1 inch of mercury; but the abnormal disturbing effects of opening the thorax cannot be accurately estimated (Ludwig).

The force of the blood-current in the arteries, or the blood pressure, not only varies between each ventricular systole, and according to the strength of the heart's action in different circumstances; but it is increased by an addition to the quantity of blood already contained in the system, as when blood is artificially injected into the veins; whilst, on the other hand, it is lessened by a diminution in the quantity of blood in the body, as in cases of hemorrhage.

The influence of the respiratory movements on the pressure of the blood in the arteries, is very complex. *Inspiration*, or breathing in, is usually said to produce a diminution in the arterial pressure, and *expiration*, or breathing out, to cause an increase in that pressure. In explanation of this view, it is stated, that, during the act of inspiration, the blood enters the thorax more readily, and thus relieves the whole vascular system of tension; whilst during expiration, the difficulty offered to the entrance of blood into the chest, increases the tension in the vessels, in the arteries as well as in the veins. According to Vierordt, however, in inspiration, the readier entrance of the blood into the thorax, causes the right side of the heart, and soon, also, the left side of that organ, to become more distended, and the arterial pulse, accordingly, increases in fulness, owing to increased arterial blood pressure, during the course of inspiration; on the other hand, in expiration, from the resistance offered to the flow of blood into the chest, the right side of the heart, and soon, also, the left side, receive less blood, so that the arterial pulse, owing to diminished arterial pressure, becomes, in the further progress of expiration, smaller. With regard to the blood pressure in the arteries, Vierordt, referring to the effects of inspiration and expiration, in filling the heart with blood, states that, in the former act, the blood pressure, though at first lessened, afterwards increases, reaching its maximum at the beginning of expiration, after which it diminishes. These views are further modified by the researches of Dr. Sanderson, who states that the rise in the arterial pressure begins with the act of inspiration, and continues to increase during expiration. Moreover, by these researches, in which a very large hæmadynamometer and kymographion were used, the respiratory act is shown to consist of a period of action occupying two-fifths, and of a period of repose occupying three-fifths of the entire act; of the former period, two-thirds are taken up by inspiration, and one-third by expiration. The arterial pressure begins to increase at the commencement of inspiration, and continues to rise during expiration, at the end of which, and during the pause, it gradually subsides. In violent expiration, the vascular tension is increased; but also in the prolonged inspiratory efforts of dyspnœa.

The increased pressure from expiration is illustrated in the tension, and occasional rupture, of bloodvessels in the act of coughing. It has already been mentioned that the velocity of the blood in the arteries is slightly increased during expiration, and diminished during inspiration, contrary to what happens in regard to the blood pressure. Indeed all the conditions connected with increased resistance by friction, which diminish the velocity, increase the blood pressure; whilst those which lessen the friction and resistance, diminish the pressure and increase the velocity. All variations in the arterial blood pressure, are less marked, when the pulse is more frequent, and also as the arteries become smaller.

A double hæmadynamometer, or *differential manometer*, has been devised by Bernard, by means of which the different degrees of pressure in different arteries, or in the same artery on the two sides of the body, under different conditions, or the different pressure in the arteries and veins, can be very conveniently determined. It consists of a U-shaped tube, the bend of which is occupied by mercury, with a solution of carbonate of soda, above it, in each leg: to the two extremities, the bloodvessels to be experimented on are attached by suitable pipes provided with stopcocks. When these are opened, if the pressure in the two attached bloodvessels is equal, the level of the mercury in each side of the bend remains unaltered; and when it is unequal, the mercury falls in the leg connected with that vessel, which has the greatest pressure on its contents. For example, in the two carotids, or two facial arteries of a horse, the pressure is equal; but if the instrument be connected with one artery near the heart, and with another more remote, it is unequal. Moreover, when this instrument is connected with the same artery on the two sides of the body, division of the sympathetic nerves on the one side, is followed by an elevation of the mercury on that side, indicating a loss of tension in the coats of the corresponding vessel.

The Pulse.

The *pulse* is the well-known beat of an artery, sometimes visible to the eye, if the artery be superficial, but more commonly felt by the finger placed upon the beating vessel. Sometimes the pulse is perceptible to the individual himself, being either felt as a throbbing sensation, or heard as a noise, when near the ear. The *remote cause* of the pulse, is the force of the heart, for its beats correspond in number with the contractions of the left ventricle. Its *immediate cause*, however, is the momentary distension and recoil of the coats of the artery, propagated along the vessel from the heart onwards, after the manner of a *wave-motion*, and produced by the propulsion of successive quantities of blood into the arterial system of the left ventricle; and commencing *at the instant of closure of the mitral valve.* The force transferred to those successive quantities of blood, is partly exhausted in urging on the blood already in the vessels; but the resistance thus met with, as we have seen, diverts the force partly on to the elastic sides of the arteries, and so distends them.

This distension of the arteries occurs first in the aorta, close to the heart, but rapidly follows along the entire arterial system. It consists, not only of a lateral dilatation of the vessels, but also of an elongation. The former change is but slight in arteries which can be subjected to examination, and is too quick to be followed readily by the eye; whilst the latter is much more evident, as in the case of superficial and tortuous arteries, such as the temporals, which may be seen to become more curved during the passage of the pulse-wave along them.

The total amount of dilatation observed during the passage of a pulse-wave along a given length of the carotid artery of a dog, has been measured, by placing the artery in a tube filled with water, and having another fine upright glass tube fitted into it; the elevation of the water in the latter, at each pulse, shows an increase of $\frac{1}{22}$d of the bulk of the piece of artery so inclosed. (Poiseuille.) According to Vierordt, the increase is as much as $\frac{1}{15}$th. The mechanical effect of this combined dilatation and elongation, but especially of the elongation, of a living artery, and of its subsequent contraction and shortening, and particularly of the latter, is a movement of the vessel in its bed, a motion which is visible in superficial arteries, especially in thin and aged persons, and which can be rendered more perceptible by placing a small bristle across it. It is this change of place, or *locomotion*, of the artery, which is the chief cause of the pulse felt on placing the finger upon the vessel. The blood itself being practically incompressible, the shock of the heart's stroke upon it is communicated, almost instantly, throughout the whole blood in the arterial system; but the effect of the distension, or distension-wave, which begins in the aorta, near the heart, apparently takes a certain time to be continued onwards, for reasons to be presently explained; hence there is a certain measurable rate in the propagation of the pulse to the distant arteries. This is the theory of Marey. But the rate of motion of the distending pulse-wave is much more rapid than the motion of the blood particles themselves within the vessels, being about 30 feet per second; whilst, as already stated, the velocity of the blood is only about $10\frac{1}{2}$ inches per second in the carotid, and about $2\frac{1}{4}$ inches per second in the distant arteries. This comparison will serve to impress on the mind the fact, that the pulse-wave is not caused by the onward motion of the blood, but by a wave-motion induced in the entire column of blood, which operates in its passage, laterally, as well as longitudinally, on the coats of the arteries.

The impulse of the heart nearly coincides with the systole of the ventricles, or, rather, it happens somewhat later than the commencement of the ventricular contraction. Now, the pulse-wave passes along the larger arteries, at the termination of the ventricular contraction, *i. e.*, after the impulse of the heart is felt on the side of the chest; and it takes $\frac{1}{6}$th of a second to reach the radial artery at the wrist. Nevertheless, the pulse is felt even in the most distant parts of the arterial system, *before* the second sound of the heart is heard, whilst the cause of this sound is the sudden closure of the semilunar valves across the mouth of the aorta and the pulmonary artery. This fact, as first pointed out by Colt, refutes the following theory of Weber, once so generally adopted, as to the cause of the propagation of the pulse-wave. That physiologist supposed that the aortic semilunar valves, being closed by the backward movement of the blood near them, owing to the recoil of the walls of the aorta nearest to the heart, acted as a fulcrum, from which the blood was propelled onwards by the yet unused resilient force of the aorta, into more and more distant portions of the arterial system, so as to produce the successive wave-like distension of their coats.

This theory of Weber assumes a minor cause, in place of the greater and true one, viz., only a residual portion of the force originating in a ventricular stroke, instead of the whole ventricular impulse. The closure of the aortic valves is not essential to the phenomenon of the pulse, which occurs before the second sound, when these valves are open. But if the pulse-wave be essentially due to the direct force of the heart, communicated through the arterial blood-column acting at the *closure of the mitral valve*, so the *closure of the aortic semilunar valves* is not without effect on that blood-column, and on the arteries which contain it. When the pulse is very accurately examined, a subsidiary wave occurs after the principal one, producing the phenomena named *dichrotism* or the *dichrotal* pulse, and this, as will be soon explained, has been referred by some to the effects of the closure of these valves.

For the investigation of this and other phenomena of the pulse, instruments named *sphygmographs* have been devised. The original apparatus of Vierordt consists of a long, slender, well-balanced, horizontal lever, or measuring rod, supported, near one end, on a proper fulcrum, and having a short vertical stem projecting downwards from near the fulcrum, and ending in a little button, which rests upon the artery. To some part of the lever, near the button, are attached certain contrivances, to secure a true vertical motion; and, at its free end, it carries a short pencil, the point of which rests against an upright cylinder or drum covered with paper. To this cylinder, when the instrument is in action, a known rate of motion is imparted by clockwork; at each pulsation of the artery against the button, the lever rises and falls, and so the pencil describes an up and down line on the revolving drum of paper. In this way a series of pulsations are recorded by an up and down waved line of a peculiar character. In Marey's improved instrument, and in other still later ones, the delicacy of record is more perfect, the lever is longer and lighter, its motions are steadied by the addition of a slight spring, and the pencil leaves its tracing upon a piece of smoked glass which is moved forwards by clockwork, or upon a coil of paper which is constantly being unwound.

The waved lines traced by such an instrument show, by the number of the undulations in a given space, the *frequency* of the pulse; by the length of the up and down strokes, the *amplitude* of the pulse movement, or the *force* of the pulse; and by the greater or less inclination of these strokes from the perpendicular, or the horizontal distance between the points of commencement of the upward strokes, the *duration* of the pulse-waves. Besides this, certain variations in the lines indicate other characters, such as firmness, or tremulousness, and so forth. There is, however, one character of the pulse recognizable by the finger, concerning which the sphygmograph gives information which may be delusive, viz., the *volume of the pulse*, which may be full in very different conditions of the system. A full pulse is usually slow and strong, but it may be quick; on the other hand, a small pulse is generally quick and feeble, but not necessarily so. The pulse is wiry, thready, or small, in hemorrhage, or on approaching death. In recording the pulse movements, this instrument also indirectly measures the force and duration of the systole of the left ventricle, and the duration of the respiratory movements.

The sphygmograph has been ingeniously employed by Marey to assist in determining the cause of the pulse itself. An india-rubber cylinder, provided with internal valves, is fitted at one end to a short, and the other to a long, elastic tube. By alternately relaxing and compressing the cylinder, water, under the direction of the valves, is drawn in through the short tube, and pumped intermittently through the longer one. This latter tube is disposed in three loose horizontal coils, each of which is brought in contact with a separate sphygmographic lever, the pencils of all of which rest upon a paper previously ruled with vertical and horizontal lines, and which revolves upon one drum, common to the three pencils. The sphygmographic pencils being placed, at starting, exactly under one another, and the drum being made to revolve, three *horizontal* lines are first simultaneously traced; but when the india-rubber cylinder is repeatedly compressed, so as to inject water by separate impulses into the long tube, thus imitating the ventricular propulsion of the blood into the arteries; undulations, resembling the pulse-waves, travel along the coils of the tube, and move the three sphygmographic levers, the pencils of which record the *moment of commencement*, the *extent*, and the *duration* of the movements occurring at three different points of the tube, by up and down lines of corresponding character and form. In the first place, the line corresponding with the point nearest to the propulsive cylinder, shows a greater amplitude in its undulation, owing to the greater force of the lateral pressure on the walls of the tube at that point; whilst, in the other two lines, a progressive diminution in the vertical depth of the undulating lines, shows a gradual diminution in the pressure, in proportion to the distance from the agent of propulsion. But what is of more interest in relation to the cause of the pulse-wave, is the fact, that though the commencement of the wave, at each of the three points tested by the sphygmographs, is simultaneous, the nearer wave reaches its highest point, before the others, which reach theirs at progressively later times. This is believed by Marey to happen in the living body, and to explain the apparent retardation of the pulse movement, or distension effect, which is indicated by the pulse itself being felt $\frac{1}{6}$th of a second later in the wrist than close to the heart, although, from the practical incompressibility of the blood, the shock imparted to it by the left ventricle must be instantly propagated through the whole of that fluid, in the arteries, just as that of the india-rubber cylinder is through the equally incompressible water.

The phenomenon known as the *dichrotous* pulse, is also detected and studied by the sphygmograph. Formerly, it was supposed to be absolutely the result of disease, or of some grave irregularity; but with more delicate instruments, its presence is often detected even in healthy conditions. It is represented by a slight secondary undulation in the down-stroke of the chief or primary pulse-line. It sometimes occurs, in health, during walking, and is noticeable also in the healthy pulse, whenever, owing to the diminished tonicity of the arteries, and their defective distension, they are in a condition to obey slighter impulses communicated to the blood. In the opposite conditions of a highly tonic or distended state of the arteries, this subsidiary wave motion of the dichrotous pulse, is not perceptible. In abnormal conditions, it is a sign of a relaxed state of the arterial system, or of a loss of blood. According to Naumann, the cause of this dichrotism is the shock communicated to the blood, at the *instant of closure of the aortic semilunar valves*, which, like the sudden arrest of a fluid by the closure of a tap, produces a shock or jar, which is transmitted back through the whole column. The time of occurrence of the dichrotous pulse corresponds well with this hypothesis; for whilst the primary pulse movement is felt *before* the second sound of the heart, the dichrotous wave immediately follows it. It is, however, suggested by Marey, that this dichrotism may be due to the primary wave being checked at the lower end of the abdominal aorta, where that vessel divides into the common iliacs, owing to the fact, elsewhere referred to, that the two iliac arteries are smaller than the aorta from which they proceed, contrary to the general rule, that the area of the branches exceeds that of the parent trunk. At this point, the primary pulse-wave is supposed by Marey to rebound, and to produce a back wave, which causes the dichrotous pulsation. In support of this explanation, it is alleged, that whilst the pulse is dichrotous in all the arteries arising from the arch of the aorta, it is not so in the femoral arteries and arteries of the lower limbs, along which the primary pulse-wave only travels. But Naumann asserts that the dichrotous pulse-wave diminishes in force, as it recedes from the heart—a fact which would support his view, but be opposed to Marey's; for, in the former case, the wave is supposed to travel outwards from the heart, but in the latter, towards the heart, *i. e.*, from the lower end of the abdominal aorta. Another suggestion has been made, viz., that whilst a primary wave occurs in the blood, a secondary wave follows it in the coats of the vessels; this opinion rests upon an experiment, in which it was shown that the simple injection of a fluid intermittently into an elastic tube, produces such a double wave.

An ordinary *vigorous* pulse-line, as marked on the sphygmographic paper, consists of a series of up and down strokes, which succeed each other at regular intervals, without any dichrotous wave-line in the down-stroke. But the pulse, as is well known, presents, owing to various causes, many modifications in character, each of which is recorded by the sphygmograph. Thus, by increased frequency of the heart's action, the pulse is rendered more rapid, as in the *quick* pulse, and then the up and down strokes of the sphygmographic line become more crowded in a given horizontal space. Again, the pulse may be augmented in force, as in the *strong* or *bounding* pulse, caused by a more powerful action of the heart, as under the effects of stimuli or mental excitement, and then the length of the up and down strokes is increased. The pulse is sometimes *hard*, as when the tension of the arterial walls is increased, whether from exalted tonicity, from extreme fulness of the vascular system, or from obstruction in the capillaries, causing an obstacle to the flow of the arterial blood. This may happen either from inflammation of a part, or from the brief application of cold to the surface of the body; the coats of the arteries being already much distended, or their tonic contraction being excessive, the pulse-wave scarcely distends them further; hence the up-stroke is short, nearly vertical, and occupies but little space, whilst the line of descent is gradual and prolonged, marking the slow and difficult recoil of the vessel. Lastly, the *soft* pulse, which is met with in relaxed conditions of the system, or may be produced by hot air- or water-baths, depends on a deficiency in the quantity of blood in the arteries, or on a defective state of the tonic contraction. With such a pulse, the up-stroke is long, owing to a greater freedom of play of the elastic arterial walls; the down stroke is much prolonged, and exhibits a small secondary wave, constituting the dichrotal pulse. Moreover, the horizontal space between the commencement of each up-stroke, is diminished, indicating a greater frequency of the heart's beats, whilst, in the hard pulse, the opposite is the case; for, as already mentioned, a sympathy exists between the action of the heart and the state of the circulation; the number of its beats being diminished, but their force increased, when the capillary system is obstructed, whilst the two opposite states occur, when that system permits the easy transmission of the blood. When a hard pulse depends upon a local cause, such as inflammation, it may be accompanied by an increase in the number of beats; but when upon a general cause, such as the application of cold to the whole body, by a diminution in the number of pulsations.

The absolute duration of each pulse, as measured in time by the number of beats in a minute, is indicated on the sphygmographic paper, by the horizontal distance between the commencement of two adjoining up-strokes. This duration may vary as much as 37 per cent. in a series of beats. It varies most in the slow pulse; for the more frequent the pulse, the more equal are its beats in duration. It was very remarkable in the slow pulse produced by poisoning with digitalis. On comparing the up with the down stroke of each pulse-line, it is seen that, usually, the former has a less horizontal progression than the latter, indicating that the distension or dilatation of the arteries, which is related to the ventricular systole, takes place in a shorter time than the recoil or contraction of the vessel, which is related to the diastole. It was formerly said that the ratio between them was as 1 to 2; but, in health, the proportion seems to be, in an average pulse, only as 100 to 106; in a quick pulse, the ratio is as 100 to 136; in the slow pulse, as 100 to 80 (Vierordt). The period of dilatation varies more than that of contraction.

The influence of the *respiratory movements* on the pulse, so far as its force is concerned, has already been indicated, in describing the arterial blood pressure (p. 665). The *volume* of the pulse during inspiration, as compared with its volume during expiration, is said by Vierordt to be as 218 to 191. It is now established by the aid of the sphygmograph, that the *force* of the pulse is gradually increased during inspiration, and reaches its maximum during expiration, this fact being indicated by the gradual ascent of the *line of mean pressure*, drawn through the middle of a series of up and down strokes. The tension of the artery, on which the fulness of the pulse inversely depends, is increased during inspiration and up to the end of expiration, the pulse becoming harder and firmer, and the length of the up and down strokes shortened; whilst, after expiration, in the pause, the tension of the vessels is lessened, the pulse becomes softer and fuller, and the up and down strokes of the curves are longer. Lastly, the *frequency* of the pulse is modified during inspiration, not, as is sometimes stated, then becoming slower, but, as is shown by Vierordt, increasing in frequency, owing to the more easy supply of blood to the heart; this view is confirmed by Sanderson, who, moreover, points out that this increase of frequency continues up to the end of expiration, as is indicated by the greater closeness of the up and down strokes in the horizontal space representing the period of the inspiratory and expiratory acts, as compared with those registered in the space representing the pause at the end of the latter. The *duration* of each pulse is longer in inspiration than in expiration.

The pulse being ultimately dependent on the heart's action, is necessarily modified in *frequency*, *strength*, and *rhythm*, by all those conditions which influence the number, strength and rhythm of the heart's beats, such as age, sex, stature, position of the body, atmospheric pressure, state of nutrition, stimulation, and excitement, as already detailed (p. 653). When the heart's action is very feeble, the pulse is said to become more evident in the smallest arteries, being propagated to a greater distance from the heart, even to the capillary vessels. This apparently anomalous result is explained by the heart's action being then too weak to distend the larger vessels to such a degree as, by their subsequent recoil, to convert the intermittent flow of the blood into a uniform and equable motion. Want of rhythm in the heart causes *irregularity* of the pulse. The so-called *intermittent* pulse indicates an ineffective ventricular systole, which is too weak to act on the arterial blood column. It may depend on a deficient supply of blood to the left side of the heart, as well as on debility of that organ. It occurs after long fasting, and is also common at puberty, in old age, and in various diseases. In healthy persons, its duration is somewhat longer than that of a single beat of the heart.

Motion of the Blood through the Capillaries.

The tissues in which capillary bloodvessels are found, and those in which they are absent, their number and size in the various tissues and organs, the varieties in the arrangement of the capillary network, and the structure of their delicate walls, are elsewhere detailed (p. 56). The form of the capillary network in different parts, has no relation to the functions of those parts, otherwise than so far as these depend on the forms and disposition of the structural elements, between—not into—which the vessels penetrate. But the closeness of the network, and the consequent number of the capillary vessels in a given space, are proportional to the activity and importance of those functions.

The capillaries form the intermediate blood channels between the finest arteries and veins. When examined in the transparent part of a living animal, they are seen to be of different sizes, some conveying two or more rows, and others only a single row of blood corpuscles. Moreover, when watched sufficiently long, they are observed to undergo slow changes in diameter, so that vessels, at one time capable of conveying several rows of blood corpuscles, shrink, and no longer convey more than a single row, or even become temporarily incapable of admitting any corpuscles, so that they merely convey the liquor sanguinis. It was at one time supposed that vessels, named *vasa serosa* or *serous vessels*, constantly so small as only to admit the fluid portion of the blood, existed in all or many parts of the body; but their presence generally, which was purely conjectural, has not been confirmed. By some authorities, however, it is at least suggested that, in the cornea, capillaries may exist, which habitually convey only the liquor sanguinis (Kölliker, Hyrtl).

In watching the capillary circulation, it is seen that such vessels as have ceased for a time to convey blood particles, again dilate and admit them, and, from this alternate contraction and dilatation, a vital contractility has been attributed to the coats of these vessels. The structure of their delicate walls, however, which are composed of homogeneous membrane containing nuclei but destitute of muscular fibre-cells, negatives the idea of their possessing vital contractility; and, moreover, it has been found that no contraction, or other change of these walls occurs, on the direct application of the electric stimulus to them. Their walls are, however, elastic, and the changes in diameter of the vessels are probably due, either to disturbed conditions in the neighboring small arteries, owing to the contraction or relaxation of their muscular coat, or to movements in the tissues in which the capillaries are distributed, and in which organic muscular fibres, fibre-cells, or other contractile elements, such as pigment-cells, are frequently present. The capillaries do not, therefore, seem to exercise any mechanical influence on the circulation of the blood through them, by virtue of an active contractile force, resident in their walls; but they may adapt themselves, by their elasticity, to the varying quantities of blood, distributed to any particular part. Such conditions must occur in the opposite states of blushing and pallor of the skin; in the conditions of fulness or emptiness of the capillaries of a gland or membrane, according as it is secreting or not; and in the condition of health and inflammation, in any vascular part, such as the conjunctiva of the eyeball.

The real propulsive *cause* of the motion of the blood in the capillaries, is the same as that of the arterial circulation, viz., the ventricular systole, modified, in its effects, by the resilience of the elastic coat of the arteries themselves. Indeed, in a living animal, if the force of the left ventricle, communicated to the blood in the arteries, be arrested by pressure on, or ligature of, those vessels, the stream of blood in the capillaries soon almost entirely stagnates, and the venous current beyond them is stopped, whilst the tension or blood pressure in the arteries also ceases. Moreover, in the fish, as we shall hereafter find, the force of the single ventricle of the heart, is sufficient to propel the blood first through the gills, and then through the arteries of the body. It has been supposed that certain mutual attractions and repulsions between the blood and the tissues lying outside the systemic capillaries, or between the blood and the air in the lungs, may influence the movement of the blood through the capillaries, and even constitute a moving power in the capillary circulation. But this implies an attractive force in regard to the blood in the arterial half of the capillary network, and a repulsive force in regard to the blood in the venous half of that network, an hypothesis complex, and yet unproved.

The supposition of the existence of a local attractive and propulsive force, exerted on the blood passing through the capillaries, is held to be supported by the following facts: The gradual emptying of the arteries after death; the maintenance of the circulation in the portal system; the periodic and local changes in the circulation during secretion, or in other conditions, such as fainting and fright, or in diseases such as congestion and inflammation; the obstructive changes which occur in the pulmonary circulation during asphyxia; the great activity of this circulation, when the respiratory changes are rapid; and lastly, the fact of a circulation of blood occurring in the embryo of animals before the development of the heart (Draper). It has been further pointed out, that of two fluids contained in a capillary tube, that which has the greatest affinity for the sides of the tube, will flow along it quicker than the other, owing to mere physical action.

On the other hand it is alleged that although a healthy condition of the walls of the capillaries and of the tissues beyond them, and a healthy performance of their functions, are necessary to an unimpeded flow of the blood through these vessels, and although a *stasis* or stagnation of the blood, and a dilatation of the capillaries, accompany a state of inflammation, imperfect secretion, or defective respiration; yet such facts do not prove the existence of a special propulsive force, resident in the walls of the healthy capillaries, or dependent upon the healthy nutritive, secernent, or respiratory function; they may merely show that the capillary circulation, though dependent upon the action of the heart and arteries, may be retarded or arrested by abnormal relations between the blood and the tissues, or air, outside the capillary walls. The enlargement of the capillaries which accompanies such stagnation of the blood in them, and also the shrinking of these vessels, as the part recovers, imply an exercise of elasticity by their walls; but this cannot be, under any circumstances, a moving force in the circulation, but rather a means of adapting the size of the capillaries, to variations in their contents.

The motion of the blood in the capillaries, when observed under the microscope, in animals not too much disturbed in the experiment, is constant, equable, and regular; but the character of the movement may be modified by the dilatation or contraction of the neighboring small arteries under the action of cold or other stimuli, by obstructions in the veins, and by the condition of the heart itself. When, as already mentioned, the heart's systole is weak, the motion of the blood in the capillaries may, from the non-development of a perfect recoil in the arteries, become pulsatory; and when the heart is still more enfeebled, the blood in the capillaries may merely oscillate, or be completely arrested, or a backward current may even take place in it. These and many similar disturbances, even under the microscope, have been often erroneously referred to active influences in the coats of the capillaries, or in the surrounding tissues.

The motion of the blood in the capillaries is more rapid in the centre of each little stream, and slower at its surface, near the walls of the vessel. The existence of corpuscles in the living blood, affords the means of determining this fact; for the red corpuscles may be seen to move, comparatively swiftly, along the centre of the vessel, whilst the white corpuscles travel much more leisurely along the sides, the ratio of their respective movements being as 9, or even 17, to 1 (Weber). The outer thin, more slowly moving film, in contact with the inner surface of the capillaries, measures, under different circumstances, from $\frac{1}{5}$th to only $\frac{1}{8}$th of the diameter of the vessel. It forms the *still layer* or *space of Poiseuille*, in which the white corpuscles move slowly along, as if some special attraction retained them against the sides of the vessel, whilst the red corpuscles are hurried along the centre. This striking phenomenon may have, in part, a physical explanation; for a retardation always occurs in the movement of that portion of a fluid which is in contact with the walls of a tube, as compared with the rate of motion along its axis, this effect being due to friction in large tubes, and also to capillary attraction in small tubes. In the living animal economy, the retardation of the circumferential layer of blood in the capillaries, must have an important influence on the nutritive, secretive, and respiratory processes, all of which are accomplished within a certain range of the capillary circulation; it may merely facilitate the withdrawal from the blood, and the escape through the capillary walls, of certain necessary materials; or it may be itself an indication of nutritive, or other attractions from without, operating on the stratum of fluid lying next to the thin capillary walls. Some such attraction may prevail between the pale corpuscles and the walls of the vessels themselves, but the existence of this has not been established. These corpuscles, however, appear to be naturally much more adhesive than the red corpuscles, as is shown by their clinging to a glass slide or cover, as seen when a minute drop of blood is spread out and examined under the microscope.

The actual rate of motion of the blood in the capillaries, as watched and measured by aid of the micrometer in the field of the microscope, in the case of individual blood particles, has been found by various observers to be, in the frog's web, rather more than 1 inch per minute, in other words, about $\frac{1}{60}$th of an inch per second (Hales, Valentin, Weber). As to the warm-blooded animals, the rate of motion is higher, being, according to Volkmann, 1.8 inches per minute in the dog; whilst the observations of Ludwig and Vierordt on the entoptical retinal image, or image of Purkinje, give a velocity in the retinal capillaries of their own eyes, of from about $1\frac{1}{5}$th inch to rather more than $1\frac{3}{4}$ inch per minute. The average velocity in Man might therefore fairly be estimated at about 2 inches per minute, or $\frac{1}{30}$th of an inch per second, *i. e.*, twice the velocity in the frog. The apparent rate of motion of the blood in the capillaries of either a warm or cold-blooded animal, as seen under the microscope, is so high that the observer is apt to be misled with regard to its actual velocity; and, deceived by the apparent motion, to doubt that the real velocity is only 1 inch per minute in the cold-blooded animal, and 2 inches per minute in the warm-blooded animal. But the area of observation being enormously magnified, the apparent or angular motion of the blood before the eye of the observer, is increased in the same proportion; so that in the field of a microscope magnifying 180 diameters, the rate of motion of the capillary blood *appears* to be, in the frog, 180 inches per minute, or 3 inches per second, and in the warm-blooded animal, to equal twice that velocity. The actual slow rate of motion of the blood through the capillaries, is remarkable and important in connection with the nutritive, secernent, and respiratory functions, giving ample time, as it were, for the important interchanges between the blood and the tissues, or the air, which take place in them, especially for those of deoxygenation and oxygenation, which occur, the former in the systemic, the latter in the pulmonary capillaries.

The slow rate of motion of the blood in the capillaries, is even more striking, when it is compared with the rate of motion in the arteries, which, as already mentioned, is estimated at about 10 inches per second, or 600 inches per minute, in the human carotid, so that the velocity of the blood in the systemic arteries, is 300 times greater than that in the systemic capillaries. It has been calculated that in the pulmonary capillaries, the rate of motion of the blood is five times greater than the average rate in the systemic capillaries, *i. e.*, 10 inches per minute, or the $\frac{1}{6}$th of an inch per second.

This remarkable retardation of the blood in the capillary vessels, as compared with its velocity in the arteries, is doubtless in part due to increased friction, dependent on the vast increase in the number of channels through which the blood now has to pass; but its chief cause is the very great increase in the *capacity* of the capillary, as compared with that of the arterial system. It has already been stated that the combined sectional areas of the first and second degrees of arterial branches, as a rule, slightly exceed the sectional area of their common trunk. In the smallest arteries this is doubtless much more marked; and on arriving at the capillaries, the increase in the total sectional area of the bloodvessels, or, as it is otherwise expressed, in the capacity of the capillary system, is sudden and immense. A fluid moving from a small into a wider tube or channel, has its motion retarded accordingly; and the change of capacity, in passing from the arterial to the capillary system, has been compared to that which would take place in a very short cone. The relative areas of the two systems of vessels, are usually, indeed, estimated, as bearing an inverse ratio to the measured velocity of the blood in them. Hence, according to the preceding data, the sectional area of all the capillaries in the human body, would be at least 300 times greater than that of the chief arterial trunks. It has also been calculated to be about 400 (Volkmann), 500 (Donders), and even more than 800 times (Vierordt), greater than the area of the aorta.

Motion of the Blood through the Veins.

The position and structure of the veins, and of their valves, have been described in pp. 25 and 54. Their walls, though thinner, and more easily compressible, than those of the arteries, and less elastic and contractile, are very strong, the vena cava having been found to require a greater force to burst it than the aorta. Collecting the blood from the capillaries by minute venous radicles, the systemic veins convey the dark blood, from all parts of the body, back to the right auricle of the heart. In the limbs, the superficial veins lying beneath the skin are not subjected to the pressure of muscles; whereas the muscles must press upon the sides of the deep veins. The pulmonary veins, which convey bright blood from the lungs to the left auricle, are peculiarly circumstanced, being, like the pulmonary arteries, situated entirely within the chest.

The blood in the veins, as indicated by opening a vein in the living body, moves by an even flow, destitute of any pulsatory or jerking movement; for the rhythmic character of the heart's action is already lost in the capillaries, and the equable flow of blood in them, necessitates a corresponding equability in the motion of the venous blood. But the primary force which urges on the blood in the veins, is still the heart's action, modified by the resilience of the arteries, which, after having nearly exhausted itself, in propelling the blood through the capillaries, is still adequate to move on the blood in the veins.

The chief resistance in the circulation of the blood, takes place in the capillaries, where, doubtless, it is very great; indeed, the force of the blood in the veins, as measured by hæmadynamometers fitted into those vessels, varies from $\frac{1}{10}$th to $\frac{1}{20}$th of that of the blood in the corresponding arteries. (Poiseuille.) In the dog, the blood pressure in the jugular vein, is from $\frac{1}{11}$th to $\frac{1}{12}$th of that in the carotid artery (Valentin); but the blood pressure diminishes, in proceeding from the branches to the larger veins, and in the great veins close to the heart, the pressure is scarcely appreciable. But certain facts seem, nevertheless, to show that this force is really the residue of that of the left ventricle, which is therefore an adequate cause, and probably the true cause of the motion of the blood in the veins, towards the right auricle. First, pressure upon *all* the arteries of a given part, arrests the flow of blood from a wounded vein belonging to the same part. Secondly, if the venous circulation from a given part, be entirely arrested, by pressure on, or ligature of, the veins, the blood pressure in them is said to rise, so as even to be equal to that in the corresponding arteries (Magendie). Thirdly, as already stated, when the heart's action is weakened, its rhythmic force is propagated into the capillaries, giving a pulsatory movement to the blood contained in them, and so establishing the fact that the heart's action extends to that part of the circulation; but, besides this, under certain conditions, oscillations occur in the blood pressure in the veins, as indicated by the hæmadynamometer. Fourthly, water injected into the arteries, with a force less than that of the heart, returns through the veins. Lastly, it has been shown by Dr. Sharpey, that defibrinated ox's blood injected into the thoracic aorta of a dog, passes freely back by the veins of the lower limbs; also, that if the aorta be tied in the abdomen, below the origin of the arteries of the stomach and intestines, the blood still returns along the inferior vena cava. In the former case, the blood passes through a single capillary system, namely, that of the lower limbs, whilst, in the latter, it is propelled through two sets of capillary vessels, viz., through those of the alimentary canal, into the portal venous system, onwards through the capillary plexuses of the hepatic lobules, and then through the hepatic veins into the vena cava inferior. The pressure employed in these experiments, as measured by the hæmadynamometer, was maintained at about 6 inches of mercury, which is known to agree with the force of the left ventricle in the living dog. To propel the blood through the pulmonary arteries, capillaries, and veins, a less force was sufficient. From the preceding considerations and experiments, the adequacy of the heart's force, to complete the circulation of the blood back to itself, may therefore be considered as established. The position of this organ in the centre of the circulatory system, its large muscular mass, and the proportionate thickness of the right and left ventricles to the work which each has to perform, likewise favor the conclusion that the heart, when present, is the real agent in the circulation of the blood. A circulation also takes place, however, in so-called acardiac embryos, in which the heart is absent, though in some of these, the movement of the blood may depend on the action of the heart of a conjoined embryo. Again, in the early embryo of the chick, a movement of the blood in the so-called vascular area, is noticeable before the heart begins to pulsate; but this movement is irregular, and takes place from the vascular area towards the embryo. Moreover, as we shall hereafter see, a true circulation takes place, in contractile vessels, in certain of the lower animals, which are destitute of a heart. Lastly, in plants, examples are met with of a circulation independent even of contractile vessels or cells. The advocates of the existence of a force, originating in the capillaries or their neighborhood, relying on these and other facts already mentioned, of course suppose it to be superadded to that of the heart in the venous circulation.

The motion of the blood in the veins, and its consequent return, through them, to the heart, are *aided*, in Man and the higher animals, by certain secondary or so-called adjuvant causes, such as the pressure of the muscles, and the thoracic respiratory movements.

In a few exceptional cases the veins themselves possess a power of rhythmic contraction; the veins in the delicate ears of the rabbit have been seen to pulsate; in the bat's wings, the veins contract from 8 to 10 times in a minute (Wharton Jones). The caudal vein of the eel, the portal veins of the myxine, and some of the abdominal veins of the amphioxus, are also pulsatile at certain points.

The effects of muscular pressure, considered as an aid to the circulation, are entirely due to the presence and direction of the valves in the interior of the veins. These are found chiefly in the veins of the limbs, especially in the superficial veins, and also in the large veins at the root of the neck. Furthermore the free edges of the valve-segments being turned towards the heart, in the direction of the venous blood-current, the valves allow the return of blood to the heart, but are speedily closed, when any obstacle to the onward flow of the blood occurs, as when a vein is compressed between a valve and the heart. Under such circumstances, the reflux of the blood in the veins, from its trunk to its branches, is checked, and on any additional pressure, the blood contained in the veins, is urged on toward the heart. Moreover, owing to the frequent anastomoses between neighboring veins, some of the blood may also be pressed into collateral channels, which are not subjected to pressure, and so be aided in its progress to the heart. This is exemplified by the increased quantity of blood forced into the superficial veins of the limbs, during muscular efforts which compress the deep-seated veins. In the actions of different muscles in the various movements of the body, sometimes one set of veins, sometimes another, must be compressed; and the varying degrees of compression to which the deep-seated veins especially are subjected, must assist or hasten the return of blood to the heart. But this is not an essential cause of the venous circulation, for that is perfectly performed during the most complete rest of the muscles of the limbs, as in the state of repose, sleep, and paralysis; moreover the circulation through the brain is performed altogether independently of muscular pressure, and of the presence of valves in its veins. When, owing to muscular exertion, a larger quantity of blood is returned to the heart in a given time, the frequency of the heart's beats is always increased, a mutual adaptation being thus evidenced, between the rapidity with which the blood is returned to the heart, and that with which the heart endeavors to transmit it onwards.

The respiratory movements have been long believed to aid in the systemic circulation of the blood. Unlike the pulmonary circulation, the systemic circulation is partly performed within, but partly, and chiefly, without, the thorax; hence, different portions of it are unequally affected or disturbed by the thoracic movements. It has already been stated that during, and almost to the end of *expiration*, the blood pressure in the systemic arteries is increased; the effects of this increased pressure have even been recognized beyond the capillaries, in the veins; for the flow of blood from a divided vein becomes stronger at each expiration. But expiration, though it aids the arterial current, must, when the continuity of the veins is perfect, retard the venous current; for the chest-walls must then compress the contents of that cavity, including the right auricle and great venous trunks, and so hinder or check the flow of blood into them. This is shown by the accumulation of blood in those veins, by the congestion of the face, and by the distension of the veins of the neck and forehead, during expiratory efforts, such as coughing or sneezing, and holding the breath, with or without some other accompanying effort. The expiratory thoracic movements cannot, therefore, be regarded as contributing to the venous circulation, the effect on the blood in the arteries being more or less counterbalanced by that on the blood in the veins. The *inspiratory* movements increase the arterial blood pressure without otherwise affecting the blood-current in the arteries; because the semilunar valves prevent regurgitation towards the thoracic space. But the absence of similar valves at the entrance of the venæ cavæ into the right auricle, so far permits the influence of inspiration on the blood in the great veins, as to facilitate its entrance into the thorax, *i. e.*, into the great venous trunks and the right auricle of the heart.

If a bent tube be inserted into the jugular vein of an animal, and its lower end be dipped into fluid, the latter will be found to rise within the tube, at each inspiration, sinking again, even a little below its original level, during expiration. (Sir D. Barry.) The blood pressure, as measured by the hæmadynamometer, has also been shown to be less, by from 3 to 7¾ inches, in the veins during inspiration, especially in those near to the chest; in the sciatic vein, on the other hand, it is no longer observed. If the veins had rigid walls, the effect of inspiration in drawing the venous blood into the thorax, would be considerable; but the collapsible character of their coats, and their yielding on pressure, prevent this exhausting process. At the root of the neck, the great veins are more or less supported by, or attached to, the bones or other parts, and so may be partially maintained in a pervious condition. The effect of inspiration is, indeed, limited to the large veins close to the thorax; for, as we have seen, the blood pressure in the more distant veins of the limbs is not increased during inspiration. It is this suction force towards the chest, during inspiration, which has been named, in regard to its effect on the circulation, the *vis a fronte*, in contradistinction to the *vis a tergo*, derived mainly from the heart, modified by the arteries, possibly aided by the nutritive and respiratory work accomplished through the capillaries, and certainly assisted by muscular pressure. The existence of this suction force towards the thorax, and its influence on the venous blood-current, are illustrated by the accidents which have sometimes occurred in surgical operations in the region of the neck, when air has been drawn in through wounded and patulous veins, and has occasionally caused death. Horses have been often killed by blowing air down the jugular vein. The right side of the heart is, in such cases, found filled with frothy blood. The cause of death is probably due, not to paralysis of the muscular fibres of the heart, but to the mechanical impossibility of the passage of frothy blood through the capillaries of the lungs.

The presence of valves in the veins near the heart also contributes to the intermittent aid given to the venous circulation by the respiratory movements; for, whilst they permit, during inspiration, the influx of blood through the large veins into the chest, they prevent the reflux of the blood in them during expiration, so that the balance of advantage is in favor of the return of the venous blood. The valves of the jugular veins not only serve this purpose, but also prevent the regurgitation of the blood towards the brain, during coughing, or other efforts accompanied by violent expiration or compression of the chest. This reflux motion of the blood in the great veins of the neck is shown by alternating conditions of fulness and emptiness of those vessels, synchronous with expiration and inspiration, producing the so-called *respiratory pulse.* In cases in which portions of the skull have been removed in the living body, and in which the veins within the cranium, protected from atmospheric pressure at their sides, may be compared to the tube in Sir D. Barry's experiment, an alternate rising and sinking of the brain have been observed, corresponding respectively with the movements of expiration and inspiration. These movements must be distinguished from the slighter pulsatory movements coincident with the heart's action, and dependent on the pulse of the cerebral arteries. In constrictive disease of the valved orifices of the heart, the return of blood into that organ from the veins, is impeded, and those vessels, accordingly, become permanently distended near the heart. Such disease almost always affects the orifices on the left side of the heart, and its effect on the great systemic veins is communicated backwards, indirectly, through the pulmonary circulation. Even in the healthy condition, the imperfect closure of the tricuspid valve causes a venous pulse at each ventricular systole, the shock being conveyed through the blood in the right auricle, and thence into the veins of the neck, as far as the first set of valves.

The effects of *gravity* on the venous circulation, or rather on certain parts of it, have been sometimes erroneously estimated; for it was imagined that the upward current through the veins in the lower part of the body, *i. e.*, below the heart, was resisted by the weight of the column of blood below that organ; whilst the venous circulation in the upper half of the body, *i. e.*, above the heart, was thought to be aided by the weight of the corresponding column of venous blood. But the circulation of the blood being performed in a *closed* system of vessels, consisting, as it were, half of arteries and half of veins, which meet in the capillaries, the weight of the venous blood in the lower limbs, is counterbalanced by that of the arterial blood. Hence, the gravity of the venous blood does not, *per se*, offer such an obstacle to the circulation, as requires to be overcome by the force of the heart; for the two columns of blood balance each other hæmostatically, like columns of water in a U-shaped tube. With regard to the vessels above the heart, they also form a double closed system, and the advantage of gravity on the venous side is, so far as the heart's action is concerned, counterbalanced by the disadvantage on the arterial side.

Gravity, however, does actually affect the circulation, through its influence on the circulatory organs, especially on the capillaries and veins; for these vessels are not rigid, like a U-shaped tube, but yielding. The weight of the entire column of venous blood, for example, is supported by the coats of the veins, those of the lower limbs having more weight to bear than the veins of the trunk, and these again more than the veins of the upper limbs, neck, and head. Hence, the coats of the veins, in the lower limbs, especially those of the less supported subcutaneous veins, are proportionally thicker than those in the upper parts of the body, the coats of the jugular vein being very thin, and those of the saphenous vein very thick, in proportion to their size. Hence, too, the valves are more numerous, and of greater strength, in the veins of the lower limbs than in those of the upper limbs; whilst in the neck, they exist only in the neighborhood of the chest. The mechanical effect of these valves is to save the entire length of the vein from the total pressure of the venous column, and to divide it into shorter subordinate columns, into which, however, weight is still transmitted by the collateral veins. When the valves of the veins of the lower limbs are weakened, and no longer close perfectly, those vessels become distended, and *varicose.* If the tonicity and elasticity of the smaller veins be impaired, or overcome, by prolonged over-distension, from obstructions to the return of blood from them, or by general debility, the fluid part of the blood is liable to escape through the coats of the capillaries and minute veins, so as to cause *dropsy.*

The *rate of motion* of the blood in the veins is much quicker than that in the capillaries; but not so quick as in the arteries. In the jugular vein of a dog, the rate of motion has been estimated at $6\frac{4}{5}$th inches per second. (Volkmann.) Considered generally, the average velocity of the blood in the veins is said to be from $\frac{1}{2}$ to $\frac{1}{3}$ of that of the blood in the corresponding arteries; this estimate is founded on the supposed relative capacity of the venous, as compared with the arterial system, which is believed to be as 2 or 3 to 1. As the velocity of the arterial blood diminishes in the smaller arteries, partly in consequence of friction, but also owing to the increased capacity of the branches in comparison with the trunks, so inversely, as the veins diminish in capacity from their branches to their trunks, the velocity of the blood in them increases as it approaches nearer and nearer to the heart, and, in the larger veins, becomes equal to about $\frac{3}{4}$ths, or more, of the velocity in the corresponding arteries. The form of the entire vascular system has indeed been likened to two bent cones, joined at their apices in the heart, and at their bases in the capillary system. The quantity of blood received by the right auricle, closely agrees with that thrown from the left ventricle; hence, therefore, the velocity of the venous current, as it enters the right auricle, must be less than that of the arterial blood passing through the aortic orifice; for the combined areas of the two venæ cavæ are greater than the area of the aorta.

The rate of motion of the blood in the veins, is more subject to *disturbing causes*, whether of acceleration or retardation, than in any other part of the circulation. Thus, the effects of muscular pressure, though, on the whole, favorable to the onward flow of the blood in the veins, are necessarily intermittent, according or not as the muscles are at play. Again, the opposite influences of expiration and inspiration, though felt only within a certain distance of the thorax, and so affecting the rate of motion of the blood in the large veins only, are themselves liable to great variations, according to the activity, violence, or depth of the inspiratory or expiratory movements. Such variations occur constantly during life, and incessantly alter the rate of motion of the venous blood-current. In experiments on animals not subjected to the continued and uniform influence of chloroform, the struggles, and the respiratory efforts of the creature, greatly disturb the velocity of the venous current, sometimes checking, sometimes accelerating it. Individual estimates of the velocity of the blood in the veins, must therefore be accepted with some reservation.

There are certain *peculiarities in the venous circulation* of particular parts of the body. Thus, the *portal* circulation is peculiar, from the fact that the blood passes in it, through a second capillary network, before it returns to the heart; for the blood which circulates thus through the liver, has already been driven through the capillary vessels of the other abdominal organs of digestion. There are no valves in the portal or hepatic veins; but the latter are retained constantly in a pervious state, by their adhesion to the substance of the liver, a condition favorable to the passage of the blood from that organ. Again, the circulation within the cranium presents peculiarities; the arterial trunks which enter it, four in number, are of large size, traverse bony passages in their way to the cranial cavity, and unite by anastomoses in the interior of the skull, at the base of the brain, all which arrangements are calculated to secure a full and free supply of blood to the brain, under various conditions of external pressure, or other impeding causes. Besides this, the proper arteries of the brain ramify, in an unusually tortuous manner, upon its complex surface, and at last divide, in the pia mater, into a close web of numberless branches supported by a delicate cellular tissue; from these, long slender minute vessels enter the brain at all points, insuring a perfect supply of blood, and its even and gentle entrance into the delicate cerebral substance. The veins within the cranium present special modifications; first, they have no valves; moreover, the largest venous channels consist of passages between layers of the dura-mater, the fibrous membrane which immediately lines the skull; hence, they are not subjected to accidental pressure, such as might interfere with the blood-current within them. Lastly, as the cranium itself has unyielding walls, the circulation of the blood through the brain is carried on under very peculiar conditions, as compared with that of other organs, which are subject to atmospheric, and perhaps muscular pressure also. The brain and the blood being incompressible, the quantity of blood within the cranium must either be always the same, or else some special provision must exist for its increase or diminution in quantity. It has been suggested that the quantity of blood in the cranium is absolutely unalterable, and that the only changes which can take place in the cerebral circulation, are various compensatory displacements of the blood in the interior of the arteries, veins, and capillaries; but experiments have shown that the brain of an animal may be rendered pallid, *i. e.*, may be deprived of the blood in its vessels by extreme venesection. Moreover, the presence of the cerebro-spinal fluid (p. 235), and the known rapidity with which the secretion and absorption of so diffluent a fluid may take place, afford a feasible explanation of the mode in which variations in the quantity of blood in the vessels within the cranium may be rapidly counterbalanced.

The *pulmonary circulation* presents many peculiarities. Its arteries convey dark or deoxygenated, and its veins bright or oxygenated, blood. Neither its veins or arteries anastomose, except in their very finest ramifications; its veins have no valves, either in their course, or at their entrance into the left auricle; its capillaries are large, most numerous, and very short between the arteries and veins. As every part of the pulmonary circulation is carried on within the thorax, the flow of blood from the right ventricles, through the pulmonary vessels, to the left auricle, is, unlike the systemic circulation, equally influenced in every part, at each moment, by the varying conditions of thoracic pressure. Lastly, the loops of the pulmonary circulation are much shorter than those of the systemic vessels, and the blood takes much less time in passing through them. The velocity of the blood is greater, and the blood pressure much less.

Period of a Complete Circulation.

It has been seen that the chief cause of the circulation of the blood in Man, and in animals possessing a heart, is undoubtedly the muscular force of that organ; that the relative velocity of the blood-current in its several parts, is quickest in the arteries, slower in the veins, and slowest, by many degrees, in the capillaries, the actual rate in the large arteries being about 10 inches per second, in the small arteries probably about 2.2 inches per second, in the capillaries about $\frac{1}{30}$th of an inch per second, and in the medium-sized veins from about $\frac{1}{2}$ to $\frac{1}{3}$d of the rate in the corresponding arteries; and lastly, that the rate of movement through the pulmonary circulation is five times more rapid than that through the systemic circulation. There remains yet to inquire, in what period of time the complete circulation is performed, that is to say, in what time, a given minute portion of blood, thrown from the left ventricle, or passing any other given point of the circulation, will flow through the body and lungs, back to the same point. The conclusion arrived at on this subject, based on many experiments in animals, is, that, in Man, a complete circulation of a given particle of the blood may be performed within a much less time than one minute. A solution of ferrocyanide of potassium (selected for the facility with which it may be detected by appropriate chemical tests), being injected into the right jugular vein of a horse, successive portions of blood are drawn from the opposite jugular vein, and subsequently tested; the presence of the salt has been detected in the portion of blood so drawn, at the expiration of 30 or even of 20 seconds. (Hering.) In such an experiment, the ferrocyanide of potassium could not have passed through the tissues across the neck, from one vein to the other, but must have proceeded with the blood along the right jugular vein, to the right side of the heart, thence, through the pulmonary vessels, to the left side of that organ, next through the aorta, carotid arteries, and capillaries of the head and neck, and thence along the veins into the left jugular; in other words, it must have performed, with the blood, a complete circuit through the lesser circulation in the lungs, and through that part of the greater circulation which belongs to the head and neck. The passage of the ferrocyanide of potassium, from the jugular vein, through the lungs, and thence, through the hinder limbs of the horse, to the great saphenous vein of the thigh, takes place in 20 seconds; and, from the same vein, to various arteries of the body, in still shorter times, viz., to one of the facial arteries in 10 seconds, but to more distant arteries, as *e. g.*, to the metatarsal in the hind limb, in from 20 to 40 seconds. (Hering.)

Similar experiments have been made, but on an improved method, by arranging a series of small cups on a rotating apparatus, so that they can be quickly moved in succession, before an aperture in a vein; in this way, the blood is collected at very short and exact intervals. The time occupied in a complete circulation of the blood, can thus be determined even in small animals. In them, speaking generally, the passage of poisonous substances injected into the veins, takes place more quickly than in the horse. In the dog, the time is found to be 16.7 seconds; in the rabbit, nearly 7.79 seconds; in the cat, 6.69 seconds, and in the squirrel, 4.39 seconds; in the horse, it is 31.5 seconds. (Vierordt.) Allowing for the obvious effect of size, and consequent length of the bloodvessels, it must be concluded that the blood in the human body performs the complete round of the circulation, in even less than half a minute.

Vierordt has pointed out a remarkable relation between the frequency of the pulse, that is, of the heart's beats, in different Mammalia and Birds, and the ascertained average of the complete circulation in them. The frequency of the pulse in these animals increases, generally, as their size diminishes, being, for example, in the horse, dog, cat, rabbit, and squirrel, respectively, 55, 96, 240, 220, and 320 in the minute, or 60 seconds. But, as we have seen, the times of a complete circulation in them are, 31.5, 16.7, 6.69, 7.79, and 4.39 seconds. From such data, it is shown, that a complete circulation, in these several animals, is performed during the following numbers of heart's beats; viz., 28.8, 26.7, 26.8, 28.5, 23.7. Thus, in the horse, for example, as 60 sec. : 55 beats : : 31.5 sec. : 28.8 beats. In the larger Birds, nearly the same proportion prevails; and the mean relation is found to be about 27 heart's beats for each complete circulation.

In Man, Vierordt calculates that, with the pulse at 72 per minute, the heart's beats are 27.7 for each complete circulation, which is accordingly performed in 23.1 seconds, or less than half a minute. Thus as 72 : 60 : : 27.7 : 23.1.

Every portion of the blood does not complete its circulation in exactly the same time. As regards the pulmonary circulation, but little difference can occur, whether a given portion of blood passes through the right or the left lung, or through this or that portion of either lung, on its way from the right to the left cavities of the heart; but even here, certain differences in the length of the route pursued by different portions of blood, must exist. In the systemic circulation, however, the differences are much more marked; the shortest route through which a portion of the blood has to pass from the left to the right cavities of the heart, is that through the nutrient vessels of the heart itself, and the longest route, that through the vessels of the lower limbs. Different portions of the blood have, indeed, to circulate through arches of varying length, and hence the time which they take to traverse different parts of the body must be somewhat different.

The slow rate of motion of the blood through the capillaries, only 2 inches per minute in warm-blooded animals, appears, at first sight, to be opposed to the above-mentioned conclusion as regards the high rate of velocity of a complete circulation; for in that circulation, the blood passes through two sets of capillary vessels, pulmonary and systemic, besides traversing the arteries and veins of these two circulations, as well as both sides of the heart. But it has been estimated that the systemic capillaries of any given organ or tissue of the body, numberless as they are, cannot measure, from the finest arteries to the finest veins, more than about $\frac{1}{10}$th of an inch in length; the pulmonary capillaries must be still shorter. According to Vierordt, the systemic capillaries do not measure, on an average, more than $\frac{1}{50}$th of an inch in length, although these limits are not well defined. The blood may, therefore, pass through both the systemic and pulmonary capillaries in a period of about $3\frac{1}{2}$ seconds only (viz., in 3 seconds through the former, and in $\frac{1}{2}$ a second through the latter named vessels). Assuming with Vierordt, the total period of a circulation at about 28 seconds, in a man of average height, this would leave a balance of $24\frac{1}{2}$ seconds for the passage of the blood through the arterial and venous channels and the heart. Supposing the mean length of the arteries and veins to be, in a man of average stature, 30 inches, and the average velocity of the blood in the arteries to be 6 inches per second (the extremes being 10 and $2\frac{1}{4}$ inches), the time required for the passage of the blood through the arteries, would be 5 seconds, and through the corresponding veins, the velocity in which is estimated as being $\frac{1}{2}$ to $\frac{1}{3}$d that of the arteries, the time would be $12\frac{1}{2}$ seconds, making in all $17\frac{1}{2}$ seconds for the circulation through the systemic arteries and veins. To this must be added a period of $3\frac{1}{2}$ seconds, for the passage of the blood through the pulmonary arteries and veins (the rate of motion in them being said to be five times more rapid than in the systemic arteries and veins), making a total of 21 seconds. This, with the $3\frac{1}{2}$ seconds above mentioned as required for the pulmonary and systemic capillary circulations, equals $24\frac{1}{2}$ seconds, or rather more than the 23.1 seconds allowed for the complete circulation. These numbers, though only approximating to the truth, still show that the slow rate of the blood in the capillary portion of the circulation, or in the area of nutritive and respiratory interchanges, is quite consistent with the ascertained rapidity of the circulation, considered as a whole.

The circulation of the blood is said to be generally, but not always, accelerated by an increased frequency of the heart's action. As life advances, it becomes slower.

Quantity of Blood in the Body.

The total *quantity* of blood in the body has been the subject of much investigation and discussion. The estimates of the older authors, for the most part, were too high, whilst some of those of later writers probably err in the opposite direction. The actual quantity in a man of average height and weight has been supposed, by some, to be 26 or 30 lbs., and by others only 12 lbs. The ratio between the weight of the blood and the weight of the body, the blood included, has been estimated, by some authors, as 1 to 4½, and, by others, as 1 to 13; according to these proportions, which differ so widely, the total quantity of blood in the body of a man weighing 150 lbs., would be either upwards of 33 lbs., or only about 11½ lbs.

Observations on the quantity of blood lost in hemorrhages, are not considered trustworthy, since in slow bleedings large quantities of fluid are absorbed from the tissues, to refill the emptying vessels, and so add largely to the amount of blood that may be drawn. The quantity of blood escaping from the vessels in decapitated criminals, added to that which may be subsequently expelled from the vessels, by cautious injections of water, gives a more accurate result. But careful experiments on animals are of most value. The method of Herbst, which consists in quick bleeding from many vessels opened simultaneously, gives the proportionate weight of the blood to that of the body, as from 1 to 12 in the ox, 1 to 16 in the dog, and 1 to 24 in the rabbit; hence, it would appear that the larger the animal, the greater is the proportion of blood to the body. Valentin compared the specific gravity of the blood drawn from a living animal, before, and after, the injection into its bloodvessels of a given weight of water, the diminution of the specific gravity of the blood, by that quantity of water, serving as a factor in the calculation; this method gives about 1 to 4½ as the ratio to the body in the dog. Chemical substances easy of detection, having been injected into the blood, in known amounts, and the quantity, in a certain portion of the blood drawn from the vessels, having been determined, data have been obtained for calculating the total quantity of the blood; this method shows a ratio of 1 to 8 or 9 (Blake). Welcker's *chromatic* method is so called, because he estimates the amount of blood left in the body after bleeding by means of the coloring matter. A set of *standard colored solutions* is first prepared, by mixing a certain known quantity of the blood of an animal with different known quantities of water. The creature is then bled rapidly to death, and the blood so drawn is weighed. The residual blood in the vessels, is then estimated in the following manner: the vessels are washed out with free injections of water; the whole body of the animal is likewise divided into small pieces, and macerated, so as to extract all the cruorin in it;

these aqueous solutions are then mixed together and measured, and the tint of the mixture is compared with the standard solutions, and thus the quantity of blood in it is determined. In this way, the proportion of blood to the body, in the dog, is estimated at about 1 to 12.

The quantity of blood in the body has been calculated by Vierordt, by multiplying the quantity supposed to be expelled from the left ventricle at each systole, by the number of times the heart contracts during a complete circulation of the blood through the system. The mode in which the latter datum is obtained, has already been explained (p. 685–6); the former is thus arrived at. The average velocity of the blood in the human carotid artery is assumed to be equal to that in the carotid of a dog, and the sectional area of the vessel being known, it is easy to determine by multiplying one into the other, the quantity of blood which passes through any part of that artery in a second. Thus 261 millimetres, the velocity of the current in the carotid per second, $\times$ .63 square centimetres, the sectional area of that vessel, $=$ 16.4 cubic centimetres, the quantity which passes through a certain part of the vessel in one second. The quantities passing per second, in the innominate, left subclavian, arch of the aorta, and coronary arteries of the heart, are then estimated in the same way, the rate of motion of the blood in the aorta being assumed to be $\frac{1}{4}$th faster than it is in the carotid. By these steps, Vierordt arrives at the conclusion that the quantity of blood projected through the orifice of the aorta from the left ventricle, every second, is 207 cubic centimetres, or 219 grammes in weight, or nearly $7\frac{3}{4}$ oz. av. But as the heart beats 72 times in a minute or 60 seconds, there occur $1\frac{1}{5}$th systoles in each second of time; hence, the quantity of blood thrown into the aorta at each systole, is about 180 grammes, or rather more than 6.3 oz. (p. 651).

As all the blood in the body must pass once through the aorta in every complete circulation of that fluid, and as this requires 27.7 systoles to accomplish it, the quantity thrown at each systole, or 180 grammes, $\times$ 27.7, the number of heart's beats, gives for the total quantity of blood in the body, 4986, or, in round numbers, 5000 grammes, which are equal to about 11 lbs. av.; this, compared with the average weight of the body, taken by Vierordt at 140 lbs., is about as 1 to 12.6. The proportion finally adopted by Vierordt, as prevailing throughout the warm-blooded Vertebrata is 1 to 13. Assuming the average weight of the adult male to be 150 lbs., the usual estimate of English writers, the total quantity of blood in the body would be about $11\frac{1}{2}$ lbs. av. It has been found that on bleeding an animal soon after feeding, nearly double the quantity of blood is obtained, as compared with the result of bleeding a similarly sized animal in a state of fasting. This circumstance may partly explain the great differences in the estimates above recorded; it also justifies the conclusion that, in certain conditions of the body, the quantity of blood in the human adult of average weight, may be even as much as 14 lbs.

The quantity of blood thrown into the aorta at each systole, which is likewise the measure of the capacity of the left ventricle, is equal to about $\frac{1}{350}$th part of the weight of the body. It would further seem that, in warm-blooded animals generally, the quantity of blood flowing through an *equal weight* of the body in a given time, is proportional to the frequency of the heart's beats. Thus, in 60 seconds, the quantities of blood which pass through 1000 parts in weight of the body, in the horse, in Man, in the dog, rabbit, and squirrel, are, respectively, 152, 207, 272, 620, and 892 parts, the frequency of the pulse in them being 55, 72, 96, 220, and 320. The ratios, accordingly, are all about as 3 to 1. The more rapid the heart's action, therefore, the quicker must be the nutritive changes in the tissues of the body; moreover, as there is no evidence of the capillaries being relatively more numerous in the smaller and quick-pulsed animals, the circulation through their vessels must be relatively quicker.

The Uses of the Blood and of its Circulation.

The blood itself is a highly complex fluid, renewed from, though not altogether formed out of, the lymph and chyle, and perfected, as we shall hereafter see, by the aid of the vascular glands and the respiratory organs. One of its offices is evidently that of providing an exceedingly elaborate material for the nutrition of every part of the body, and for the production of the various secretions which are used in the organism. The fluid character of the blood fits it for transmission through a vascular or circulatory apparatus, even through the finest vessels; and in this circulation through the body, by means of such an apparatus, its proper nutrient materials are conveyed to all the organs and tissues of the frame, into which a fluid plasma passes through the coats of the capillaries. But, secondly, besides furnishing a constant stream of nutrient material, the blood receives, by absorption into its own current, refuse and effete matters from the whole system, and subsequently transports them to proper excreting organs, by which they are thrown out of the body. Lastly, the dark venous blood receives, through the respiratory organs, a quantity of oxygen from the air inhaled into the lungs, and transports this oxygen in the red and arterial blood, to every part of the frame, either for its special stimulation, or for combination with its proximate chemical constituents, in the exercise of the functions of those parts; the returning venous blood brings back, amongst other oxidized materials, carbonic acid, and conveys this to its proper excreting apparatus, the lungs, whence it is thrown off. The circulating organs in animals are, therefore, modified, in accordance with the characters of their respiratory organs.

ORGANS AND FUNCTION OF CIRCULATION IN ANIMALS.

Vertebrata.—The Vertebrata generally, like Man, have not only a perfectly formed blood, containing colored and colorless corpuscles, but they also possess a central heart placed in a pericardium, and connected with a completely closed system of bloodvessels, consisting of arteries, capillaries, and veins. In the Amphioxus alone, there are no colored corpuscles, and the heart has no pericardium. As we have seen, the Vertebrata only have a system of absorbent vessels, which empty themselves into the bloodvessels. The size of the red corpuscles in several animals is given in a Table at pp. 69, 70.

But important peculiarities exist in the vascular systems of some of the

Vertebrata, dependent upon the structure of their respiratory organs. Thus, in Mammalia, Birds, Reptiles, and Amphibia, respiration is performed by means of lungs, and hence they are called *pulmonated* or *air-breathing* Vertebrata. These consist of two divisions, one including Mammalia and Birds, in which the temperature of the blood is high, and another, including Reptiles and the perfect Amphibia, in which the temperature of the blood is low; the former are the *warm-blooded*, *pulmonated* or *air-breathing*, Vertebrata, and the latter, the *cold-blooded*, *pulmonated* Vertebrata. Again, Fishes breathe by means of gills or branchiæ, and constitute the *branchiated* or *water-breathing* Vertebrata; they are still more decidedly cold-blooded. In such of these divisions, special modifications of the circulatory apparatus are met with, dependent on differences in the degree, or kind, of their respiration. The Class Amphibia contains animals which commence life as aquatic branchiated creatures, but which, in the adult state, become pulmonated; their circulatory organs are accordingly modified during life, and in a few, which retain, in the adult condition, both gills and lungs, the organs of circulation present a composite form. In all cases, a *portal* circulation is present.

In the *warm-blooded*, *pulmonated* Vertebrata, which include the Mammalia and Birds, the heart, as in Man, consists of four cavities, two auricles, and two ventricles, a right auricle and ventricle constituting the right side, and a left auricle and ventricle forming the left side, of the heart, the two sides being separated by a perfect intervening septum. The general distribution of the vessels is also the same. All the blood which returns from the body to the right auricle, is sent through the lungs, by the right ventricle, and on into the left auricle, before it is again distributed to the body by the left ventricle. As in the human body, there is a perfect *double* circulation.

Certain minor peculiarities are met with. Thus, the position of the *heart* is usually median, except in the orang-outang, and perhaps in other Anthropoid apes, in which it inclines to the left side, as in Man. In many Ruminants, a bony structure, the bone of the heart, strengthens the base of the ventricular septum. In the dugong, the apex of the heart is deeply notched, the ventricles being there separate; in the manatee, it is less notched.

In Man and the higher Mammalia, the chief *arteries* spring from the arch of the aorta unsymmetrically—an arrangement said to favor the distribution of blood to the right fore limbs, rather than to the left; but in the lower Mammalia, the branches arise symmetrically. In the hind part of the tail of the whale, the caudal artery runs, for purposes of protection, through the base of the echelon bones, on the under side of the vertebræ. In many climbing lemurs, in the lion and other large Carnivora, the brachial artery of the arm passes through an opening in the humerus, and thus is protected from muscular pressure; so also does the artery of the coffin bone or hoof bone in the horse.

A cluster of closely ramified arterial vessels, which frequently anastomose together, and again coalesce into a single trunk, is named a *rete mirabile.* Examples of such *retia mirabilia* occur in the carotid arteries within the cranium of the Ruminants, the effect of which may be to check the too rapid flow of blood to the brain, during grazing. Similar structures are found in the fore limbs of the climbing sloths and lemurs. In diving animals, such as the Cetacea, large *retia mirabilia* exist in the thorax, the object of which is probably to allow the prolonged suspension of respiration during the submergence of those animals.

In the higher Mammalia, as in Man, there is but one superior vena cava; but in the Pachydermata and Rodentia, there are two superior venæ cavæ, and sometimes a cross branch between them, in the neck. Suppose an enlargement of this cross branch, so as to form a left innominate vein, the blood from the left side of the head and neck and the left upper limb would pass over to the right side, whilst the trunk of the left vena cava might then be obliterated as far as the heart. In certain diving Mammalia, *venous plexuses* or *venous retia mirabilia* exist, in which the impure blood is for a time retained. The portal system in the Mammalia, is entirely unconnected with the renal veins; sometimes the portal veins have valves.

In *Birds*, the heart is very strong, and lies exactly in the middle line; moreover, the chief branches from the arch of the aorta, are also symmetrical, in accordance with the equal bilateral development, so important and typical in Birds. The veins in Birds have relatively fewer valves; the portal system communicates, by a few branches, with the renal veins; moreover, the veins of the pelvis and lower limbs likewise contribute branches to it.

In the *cold-blooded, pulmonated Vertebrata*, which comprise the Reptiles and the perfect Amphibia, the heart is reduced to three cavities; viz., two auricles and one ventricle. One auricle, the right and larger one, receives blood from the system; the other, the left, usually smaller, receives blood from the lungs; both discharge their contents into the common ventricle, which thus receives a mixture of dark venous blood from the system, and bright arterial blood from the lungs. From the single ventricle there proceed, in the Reptilia, a distinct aortic and pulmonary trunk, but in the Amphibia, only a single arterial trunk exists, from which the pulmonary arteries take their origin; in either case a part of the mixed ventricular blood again passes through the lungs, whilst most of it is propelled through the body. The blood is no longer *entirely* sent through the lungs, before it is distributed to the body again, as happens in the warm-blooded Birds and Mammals, which possess a perfect double circulation; on the contrary, a more or less mixed blood goes to the lungs, and a more or less mixed blood to the body. The pulmonary and systemic circulations are not wholly distinct, but meet in the common ventricle; the circulation is not completely double. In the highest Reptiles, the Saurians, which approach the Birds in so many parts of their organization, there exists, however, a partial ventricular septum, which, in the crocodiles, is said sometimes to be even complete. The outwardly single ventricle always gives off two arterial trunks, and the internal septum is so placed, that it serves to direct the dark systemic venous blood entering from the right auricle, chiefly into the pulmonary arterial trunk, whilst it turns the current of red arterialized blood coming through the left auricle from the lungs, towards the aortic or systemic arterial trunk. In these animals, then, the circulation approaches closely to the character of the double circulation in Birds and Mammals; but the imperfect structure of the ventricular septum may permit a certain amount of intermixture of the two kinds of blood in that cavity. The right or anterior portion of the ventricle, which is connected with the pulmonary artery, has thinner walls than the left or posterior portion, which is connected with the aorta. In the Chelonia and Ophidia, a less perfect septum also exists, but it gradually becomes smaller, and therefore less able to separate the two currents of blood, or to guide these in special directions. In the perfect adult Amphibia, the single ventricle has either only slight traces of a septum, or, more commonly, no septum whatever; the single arterial trunk proceeding from it, is sometimes named the *arterial bulb*, or *bulbus arteriosus*. Even the *auricular* septum is imperfect in the Proteus.

The arrangement of the branches of the aorta in these cold-blooded pulmonated Vertebrata, is also peculiar. In Man and Mammalia, the single aortic arch bends over the root of the left lung, and continues on as the abdominal aorta. In Birds, the arch of the aorta turns down over the root of the right lung, to become the abdominal aorta. In the higher Reptiles, two aortic arches exist, one on each side, forming a right and left aortic arch, which descend over the roots of the corresponding lungs, and join together somewhere in front of the vertebral column, to form the abdominal aorta. Of these, the right aortic arch, the only one present in Birds, is larger than the left, and evidently forms the proper systemic artery; for it gives off the arteries to the head, neck, and upper limbs, which parts accordingly receive almost entirely red blood, which is directed into the aorta, as already mentioned, by the ventricular septum. On the other hand, the left aortic arch is small, is joined by a short trunk to the pulmonary artery, which springs from the other side of the septum, and from it receives dark blood; hence it follows that the abdominal aorta, formed by the coalescence of the right and left aortic arches, carries mixed blood to the posterior part of the trunk and the hind limbs. In the lower Reptiles three aortic arches exist on each side; the upper pair give off the vessels of the head and neck, the lower pair give origin to the pulmonary arteries, and all combine, by short branches, into two descending trunks, which unite to form the abdominal aorta. Here, also, a more perfectly oxygenated blood is provided for the anterior, or more important part of the animal, a less perfectly oxygenated blood, for the hinder part.

A portal circulation exists in both Reptiles and Amphibia; it is connected with the renal veins, which also exhibit a renal portal system; *i. e.*, a set of veins, which convey blood into the kidneys for distribution in their interior. The condition of the organs of circulation in the young or immature Amphibia, will be best understood after that of Fishes has been described.

The *cold-blooded branchiated Vertebrata*, or Fishes, have no lungs; those organs being represented, however, in a few species, by the so-called *air-bladder*, an appendage, usually of the pharyngeal part of the alimentary canal. The heart is now simplified by the suppression of the left auricle, there being no pulmonary veins to end in it; the ventricle also is single, as in the Amphibia and Reptiles, but it never presents any trace of an internal septum. There remain, therefore, but a single auricle and a single ventricle. The auricle, like the right auricle in other cases, receives the dark venous blood from the body, and transmits it, through an orifice provided with valves, into the ventricle. This is very muscular, and propels the blood, not into the lungs, for there are none, nor directly into a systemic arterial trunk, or aorta, for immediate distribution through the body generally; but, on the contrary, the single ventricle sends it into a short trunk, called the *arterial bulb*, which has valves at its root, and, in a few examples, is even partially divided into two. From this bulb, a series of arched vessels, usually five, sometimes four, in number, proceed upwards, supported on the cartilaginous branchial arches, and convey the blood, through the branchial arteries, into the gills, in which it passes through capillary vessels, and is then collected by the branchial veins; these running towards the vertebral column, unite together on the dorsal aspect of the alimentary canal, to form a single systemic arterial trunk, which corresponds, in function, with the aorta of the higher Vertebrata. From this, branches are given off to all parts of the body, excepting the gills and generally, if not always, certain parts of the head, which are, singularly enough, supplied by special branches proceeding at once from the branchial veins. From the body, generally, the blood is brought back, by the systemic veins, to the single auricle. In the Fish, therefore, all the blood which returns from the body to the heart, is sent first through the respiratory or oxygenating organs, before it re-enters the system; the respiratory apparatus is so interposed that it forms a part of the general circulation, the branchial circulation being continued on to the systemic circulation, without the blood coming back to the heart between them. Hence the circulation in the branchiated Fish, is said to be *single*, as distinguished from the *imperfectly double* circulation of the cold-blooded, and the *completely double* circulation of the warm-blooded, pulmonated Vertebrata. The heart of the Fish is also said to be a *branchial* and not a *systemic* heart, because its immediate work is to force the blood into the branchiæ or gills. No special contractile apparatus exists beyond the gills, to accomplish the circulation through the body—a fact which has already been adduced (p. 674), to show that the heart's action is adequate to drive the blood through the systemic circulation of Man, and the pulmonated Mammalia. In the caudal veins of the eel, however, as already mentioned, there exists a pulsating portion, named a *venous heart*, which undoubtedly assists in the return of the venous blood to the distant *proper* heart. Its presence may be connected with the unusual length of the systemic vessels in this part of the eel; but even here, the heart propels the blood through the vessels of the gills, and afterwards through the systemic arteries and capillaries. Pulsating dilatations are likewise found in the arteries of the pectoral fins of the torpedo and chimæra, and in the portal vein of the myxine.

In Fishes, as in other Vertebrata, a portal system of veins exists; it is composed not only of the veins from the digestive organs, but also of those from the other viscera in the posterior part of the abdomen, and likewise of some of those from the hinder part of the body. The venous trunks thus formed, conduct blood to the kidneys as well as to the liver, so that, in Fishes, both these glands receive venous blood. After being distributed through them, the blood is returned to the heart, by proper hepatic and renal veins, which open into the vena cava inferior. Retia mirabilia, both arterial and venous, exist in certain Fishes, on the swimming bladder, in the eyes, and in the neighborhood of the gills and the intestines.

Since all the blood of Fishes, after its return from the body, passes through the respiratory organs, before it again proceeds to the body, it might be inferred that the respiration must be more complete in them than in the Reptiles, in which only a portion of the venous blood is transmitted to the respiratory organs, whilst some is distributed to the body again. But in Fishes, the respiratory process itself is less active than it is in Reptiles, being aquatic, instead of aerial. As the heart in the Fish is a branchial or respiratory heart, its single auricle and ventricle have been supposed to be homologous with the right auricle and ventricle, or respiratory heart, of the Bird and Mammal. This view, however, is only partially correct; for though the auricle in the Fish's heart, is homologous with the right auricle of the more perfectly formed Mammalian or Avian heart, and therefore respiratory, the single ventricle represents both ventricles of the heart of the warm-blooded Vertebrata, and, indeed, rather the left than the right ventricle. In the Fish, the branchial vessels given off from the arches, which proceed from the bulbus arteriosus, end in the systemic arterial trunk, and the branchiæ and their vessels may therefore be regarded as organs interposed in the systemic circulation. In the pulmonated Vertebrata, on the contrary, the pulmonary arteries enter the lungs, from which the blood is returned through pulmonary veins, and these latter do not unite to form an artery, but re-enter the auricular portion of the heart; so that the pulmonary system is not, like the branchial system, continuous with, or a portion of, the systemic, but altogether a special circulation.

The Amphibia begin life as aquatic branchiated animals, but most of them, in their mature state, lose their gills and acquire lungs, so as to become pulmonated and air-breathing. In this metamorphosis, not only transitions occur in the respiratory organs from the Piscine to the Reptilian condition, but also simultaneous adaptations of the circulating system. The differences in the mode of respiration, and in the character of the circulation, which are observed between two great Classes of the Vertebrata, viz., Fishes and Reptiles, are exactly paralleled by the differences met with in the immature and mature respiratory and circulatory organs, in an individual Amphibian; and the progressive steps which lead from one state to the other, can be seen in the evolution of a single animal. These changes may be traced in the frog, or in the salamander. In the tadpole of the former, *external branched gills* first appear, but soon become absorbed, and are succeeded by *internal laminated gills*, resembling those of the Fish. In this condition, the heart, composed of a single auricle and ventricle, receives the blood from the body, and propels it into a bulbous arteriosus, and thence, by three lateral symmetrical branches, or *branchial arterial arches*, into the gills; after passing through capillary vessels, it is collected by the branchial veins, from the foremost of which the arteries of the head are given off; these veins, but chiefly the second and third, combine to form the systemic artery or descending aorta, which conveys the blood into the rest of the body, whence it is again returned by the veins, to the single auricle. This form of circulation is truly Fish-like; but at the base of each branchial lamina, a minute vessel runs directly from each branchial arterial arch, to the commencement of the descending aorta; as development goes on, more blood passes through these communicating vessels, directly from the bulb into the descending aorta, without traversing the vessels of the gills; still later, the gills themselves diminish, and more and more blood passes through these little arched vessels at their base; finally, the gills and their vessels, being the one atrophied, and the other obliterated, the whole of the blood proceeding from the ventricle through the arterial bulb, traverses these enlarged symmetrical communicating vascular arches, and so reaches the descending aorta. In the meantime, from the lowermost vascular arch, on each side, there has been developed a little vessel, which ramifies on the walls of a small sac, or rudimentary lung; and as these organs are gradually enlarged, the vessels in question grow, and form the pulmonary arteries. By these, one portion of the blood from the single ventricle, is carried to the newly evolved respiratory organs, the air-breathing lungs; whilst the rest is conveyed through the remaining vascular arches, now reduced to two in number on each side, partly into the arteries of the head and neck, but chiefly into the aorta, and the body generally. Lastly, the blood returning from the lungs, enters a small superadded auricle, or left auricle, which becomes parted off from the right; whilst the blood which returns from the body, enters the ordinary right auricle. Thus is established an incomplete double circulation, precisely the form met with in the lower Reptiles. In passing to the higher Reptiles, the essential change consists in the gradual rising up of a septum within the single ventricular cavity, by which it becomes more and more completely divided into two chambers, as seen in the Saurians, and especially in the crocodile. This change, when quite complete, and constant, produces the perfectly divided ventricles, with their entirely separate pulmonary and systemic arterial trunks, as found in the heart of the Bird and Mammal. Thus are formed the four-chambered heart and the completely *double* circulation.

Similar changes, in the heart and great vessels, occur in the young newt or water salamander; but the external gills not being transitory, or giving place to internal gills, as in the tadpole of the frog, remain throughout the larval condition, becoming, at one time, very large and plumose. Like the internal gills of the tadpole, they receive vessels from the bulbus arteriosus, and, as in them, their disappearance is associated with the same changes in the future distribution of the blood, which is henceforth sent partly to the lungs, but chiefly to the body.

Certain of the Amphibia possess, in their mature condition, both kinds of respiratory organs, viz., external gills and lungs, and are hence named *Perenni-branchiata.* In these, as in the Proteus, the condition of the circulation corresponds with that found in the intermediate stages of the larval condition of the newt. Three anterior arches from the bulb supply the branchial arteries, and a fourth gives a vessel, which becomes the pulmonary artery of its own side; the pulmonary veins end in a rudimentary left auricle, and the systemic veins in a right auricle; the ventricle is single, and gives off the bulbus arteriosus, from which arise the vascular arches just mentioned.

In the somewhat anomalous Fish, the Lepidosiren, or mud-fish of the Gambia, a remarkable approximation is shown towards the perenni-branchiate amphibian form of respiration and circulation. It has six pairs of branchial vascular arches; of these, the first, fourth, fifth, and sixth, supply the branchiæ, which are filamentous, but not external, like the permanent gills of the lower Amphibia. The second and third pairs, pass as simple channels into the descending aorta, and also give off branches which unite to form a single pulmonary artery, distributed to the largely developed cellulated air-bladder. The single pulmonary vein ends in the sinus of the inferior vena cava.

The preceding descriptions indicate a unity of plan in the circulating organs of the Vertebrate series of animals, as marked as that which may be traced in their skeleton and nervous system—gradual modifications of this plan being manifested in ascending from the lower to the higher animals.

In the Amphioxus, the lowest Fish, and therefore the lowest Vertebrate animal, the circulating system retains its Vertebrate type in the arrangement of the principal vessels; but it presents the singular anomaly of not having a single central heart, but possessing instead, numerous contractile cavities situated in the course of the chief bloodvessels. Beneath the complex branchial chamber is a contractile vessel, or bulb, performing the office of a ventricle; from this, as many as fifty pairs of branchial arterial arches arise, at the root of each of which is a contractile dilatation. These numerous branchial arteries, of which the anterior ones are themselves contractile, end, as usual, in the branchial veins, which are equally numerous, and combine together to form the proper descending aorta, which is placed immediately beneath the chorda dorsalis. The foremost vascular arch, the duct of *Botal*, joins the aorta, without supplying branches to a branchial fringe. The aorta distributes branches to all parts of the body, the veins from which ultimately unite to form two venous trunks, one a portal vein, a part of which is dilated and contractile, and another which represents the vena cava inferior, on which is found a contractile sinus, pulsating rhythmically, and propelling the blood forwards into the rudimentary ventricle already described. The great number and wide distribution of rhythmically contractile cavities in the circulating system of the Amphioxus, suggest a comparison with the multiple hearts, or pulsating chambers, seen in certain Molluscous and Annulose animals. Its blood also contains only colorless corpuscles.

In the Non-vertebrate animals, the blood, and the organs of its circulation, where they exist, are peculiar, and distinguished from the same parts in the Vertebrata. The blood, in the higher forms of these animals, is corpusculated, but its corpuscles are not smooth and colored with cruorin, like the red corpuscles of the Vertebrata, but, even when the blood itself is tinged, they are usually colorless and granular, like the white blood-corpuscles and lymph corpuscles of the Vertebrata. Sometimes, however, they are flattened, discoid, or even angular; and occasionally they have a bluish or greenish tint. In the simplest of these animals, the blood contains only granules.

This common nutritive fluid, or blood, has, indeed, been regarded by some as corresponding rather with the lymph, and the vessels in which it circulates, as homologous rather with the lymphatic system of the Vertebrata. It is certain that no other vessels corresponding with lymphatics, exist in the Non-vertebrate animals; and no lymphatics have been detected in the Amphioxus, which has only colorless corpuscles. The vessels in which it circulates, present this great peculiarity as contrasted with the circulating apparatus of the Vertebrata, that they no longer form a continuous series of well-defined tubes, or true bloodvessels; but, even in the highest forms, and, to a still greater degree, in the lowest forms, the blood passes from such definite vessels into spaces lying, as it were, between the viscera and tissues of the body, furnished doubtless with a lining membrane, but not having otherwise distinct walls or coats. In the higher of these animals, these spaces form spongy recesses, *sinuses*, or *lacunæ*, and in the lower forms, merely *perivisceral* or *intervisceral* spaces.

Connected with the true vessels, in many of the higher forms, there are found one or more rhythmically pulsating contractile cavities, which are therefore called hearts; sometimes these are unilocular or ventricular, sometimes bilocular, or auricular and ventricular; sometimes they are multilocular. One of these hearts only can be regarded as homologous with the heart of the Vertebrata, in some of which animals, as in the bat, the eel, torpedo, myxine, and amphioxus, for example, portions of the venous system are also pulsatile. Pulsating cavities also exist, as we have seen, in certain Reptiles, Amphibia, and Fishes, in connection with the lymphatic system, viz., the lymphatic hearts.

When the heart in a Non-vertebrate animal is single, it is, as a rule, placed on the dorsal aspect of the body, *i. e.*, on the surface opposite to the one upon which the nervous axis is found; it is, moreover, *systemic*, or sends the blood to the various parts of the body, including the liver, and not to the respiratory organs, which only receive the blood as it is returning from the body to the heart. This is the reverse of the arrangement met with in Fishes, in which the heart is *respiratory*. In the Fish, the heart receives and transmits deoxygenated blood, whilst in the Non-vertebrate animal it receives and transmits an oxygenated fluid. When the heart is bilocular, it is constricted externally, and presents a delicate projecting border or valve between the auricle and ventricle. When the heart is multiple, the supernumerary ones are always simple or respiratory, and are placed upon the veins near the respiratory organs, any modifications of which, as in the Vertebrata, necessitate changes in the arrangements of the vascular system. A portal venous system never exists, the liver being always supplied by the systemic arteries. The vessels are named arteries and veins, according to the direction of the current within them, and not from their structure; for distinct coats, like those of the arteries in the Vertebrata, are not recognizable. Though extremely delicate valves are present in the heart, they are not found so regularly disposed in the veins, as in the Vertebrata. Sometimes a pericardium exists. True capillaries, provided with distinct walls, and intermediate between the finest arteries and the finest veins, have not been demonstrated, and in most instances are certainly absent; but, the arteries pour out the circulating corpusculated fluid, into lacunæ, or interstices, between the organs or elements of the tissues, from which it is collected into venous sinuses and trunks.

Mollusca.—The most perfect condition of the circulatory system, in the Non-vertebrate animals, is met with in this Subkingdom. and in the Class Cephalopods. In the cuttle-fish, for example, there is found a *systemic* ventricular heart, provided with valves at its orifice; it is usually rounded, has strong muscular walls, and even internal columnæ carneæ. Arteries proceed from it to all parts of the body, excepting to the branchiæ or gills, the liver even receiving branches. The blood is returned into a large vein, or venous sinus, which is surrounded by a remarkable cellular organ filled with blood, and from which symmetrical lateral branches, two or four in number, according to the number of the gills, proceed to those organs, each presenting, as it enters the gill, a pulsating dilatation, or so-called branchial heart, which helps to propel the blood through the gills. From the gills, the blood is returned into large venous sinuses, which, being contractile, act as auricles, and thence passes into the ventricular systemic heart already described. In the Pteropods and in the Gasteropods, there is but a single heart, which is always systemic, distributing its contents by one arterial trunk and numerous branches, to the body and liver, from which, having passed through *lacunæ* or spaces, it is again collected by veins, and by them conveyed to the respiratory organs; from these, it is collected by other canals, the branchio-cardiac veins, and is so brought to the heart again. In the terrestrial Pulmogasteropods, as in Helix, the venous blood from the body passes through small vessels on the walls of the pulmonary air sac, and is then collected into a larger vessel, which conveys it to the heart; whilst in the aquatic Branchiogasteropods, as in Doris, the blood returning from the body is carried, by special vessels, into the gills, and is then conveyed by other vessels back to the heart. In both kinds of Gasteropods, the heart consists of an auricle and ventricle, between which there is found a distinct but minute valve, which serves accurately to direct the course of the circulating fluid. In the Lamellibranchiata, the heart, usually single, but sometimes double, in correspondence with the bilateral arrangement of the parts of the body of these animals, and often perforated by the intestine, is placed in a pericardium, situated near the adductor muscle, which closes the shell; when single, it has sometimes one and sometimes two auricles, connected with its simple ventricle; when the heart is double, each has only one auricle.

Molluscoida.—In these animals, the circulatory organs become still more simple, or even disappear. Thus, in the Ascidioida or Tunicata, although the bloodvessels, or blood sinuses, are very complex on the walls of the peculiar respiratory atrium, the heart itself has no valves between its dilated parts or chambers, and the blood is propelled by opposite peristaltic actions, separated by an interval or pause, first in one direction and then in the other; hence the heart is sometimes systemic and sometimes respiratory, and each chamber is sometimes auricular and sometimes ventricular in function. In the compound Ascidioida, it is stated that the vessels of one animal are connected, through the footstalk or common "stolon," with those of the others belonging to the same cluster. In the Brachiopoda, there is still a proper simple heart, sometimes, it is said, two; but the circulating system is considerably reduced in extent: the numerous contractile cavities found in these animals, have not been proved to have any connection with the blood system, but rather to be comparable with the atrium of the Tunicata. Lastly, in the Polyzoa, neither a contractile heart, nor even vessels, have yet been detected; in these soft delicate animals, the nutritive fluids are supposed to permeate the walls of the alimentary canal into the perivisceral spaces, and thence to penetrate every part of the body.

Annulosa.—In the largest animals of this Subkingdom, the circulatory apparatus presents the greatest simplification. Thus, amongst the Crustaceans, a single, well-developed, muscular, *systemic*, dorsal heart is found in the lobster; it is placed in the median line, beneath the hinder border of the thoracic part of the shell, and is inclosed in a delicate sac, which, from its resemblance to the pericardium in the Vertebrata, has been so named, but which is, in reality, a venous sinus. From the heart, six systemic arteries are given off to the head, stomach, liver, and caudal extremity; from the lacunæ or spaces between the tissues and organs, the circulating fluid is collected by veins, which end in sinuses placed above the ventral surface; from these, it is conveyed, by distinct vessels, into the gills, there being sometimes contractile dilatations at the base of those organs; having passed through the gills or branchiæ, it is then returned, by the so-called *branchio-cardiac* veins, to the large venous sinus inclosing the contractile heart, into which it enters through valved apertures, and is then propelled into the systemic arteries already described. No cilia ever exist in the interior of any part of the circulating system of the highest or Arthropodous Annulosa. In most other Crustacea, the plan of the circulating apparatus, is the same as in the lobster; but in certain of the lowest forms, the simple heart is replaced by an elongated, and sometimes by a segmented, contractile vessel, or *dorsal vessel*, provided with lateral valved openings, by which the blood enters from an inclosing venous space or sinus. In Insects, the circulatory system presents, as has already been seen in so many instances, modifications adapting it to special forms of the respiratory apparatus. In them, there no longer exist either lungs or gills, but tracheal respiratory tubes ramified through every part of the body. The heart is replaced by a numerously segmented *dorsal vessel*, provided with valves between each segment, contracting rhythmically from behind forwards, and having numerous lateral valved openings, through which the circulating fluid, returned from all parts of the body, enters from an inclosing so-called pericardial, but really venous, space or sinus. The corpusculated fluid or blood, propelled from the anterior extremity of the dorsal vessel, passes, however, not so much into distinct vessels, as into channels, lacunæ, or spaces, in and between the various organs and tissues of the body, and so comes into relation with the universally diffused tracheal tubes, and then again finds its way back to the pericardial venous sinuses. The chief modification of this system, seen in the Myriapoda and Spiders, consists in the comparative length or shortness, the equal development, and the more or less frequent segmentation of the valved dorsal vessel, in accordance with the consolidation or multiplication of the segments. Thus, in the Geophilida, the number of contractile segments is upwards of 150; in Iulida, as many as 75; in Scolopendrida, 15 to 21; all are separated by well-formed valves. A small ventral trunk also exists in some Myriapoda. In the Arachnida, the dorsal vessel sometimes consists of only four or five closely packed chambers. These segments, with their interposed valves, are found only in the body of the perfect Insect, and usually number eight or less; in the thorax, the dorsal vessel has no valves, and, in front, it ends in a fine vessel, from which a few branches have been traced. In the microscopic Arachnida, such as the acari, there are no proper vessels, but the nutritive fluid contained in the perivisceral chamber, is moved by means of contractions of the muscles of the intestines and the skin. The scorpion presents the unusual condition of possessing a distinct abdominal vein, proceeding from the tail, and giving branches to the pulmonary sacs.

In the Annelida, the best anatomists agree in doubting the existence of either a contractile chamber or heart, or of a contractile dorsal vessel; the only cavities possessed by them, analogous to the more perfectly developed circulatory apparatus of the Arthropodous Insects, Myriapods, Spiders, and Crustacea, are the perivisceral spaces, lacunæ, and channels, in which a slightly corpusculated fluid has been found. It is in this Class, including the various marine and terrestrial Worms and the Leeches, that those remarkable ramified vessels are met with, extending into every segment and portion of the body, named the *pseudo-hæmal* vessels, which contain, sometimes a colorless, though usually a red-colored fluid, often corpusculated, but the color of which is not dependent on the corpuscles. These vessels are at one or many parts, dilated and contractile, and, at certain parts, lined with *cilia*. They always communicate, at some point, by a tubular stem with the exterior; a principal trunk on the dorsal aspect of the body, has been regarded as the representative of the true dorsal vessel of the higher Annulosa; but their homologies are believed to be rather with the so-called *water-vessels* of the still more lowly organized Annuloida, than with the non-ciliated vascular apparatus of the Arthropodous Annulosa.

Annuloida.—In these animals, nothing analogous to a blood system exists, there being neither blood nor true bloodvessels, or lacunar blood spaces. The *water-vessels* of the Rotifera or Wheel-animalcules, of the marine Turbellarian Worms, the Trematode Flukes, the Nematode Thread-worms, and the tape-like Tænia and its allies, the Acanthocephali, are ciliated canals, which communicate, at some point, with the exterior, and are, by some, regarded rather as respiratory organs. Neither a heart nor a dorsal vessel has been found in them. The extensive system of *ambulacral* and other vessels, possessed by the Echinodermata, also communicates with the exterior, and is, apparently, partly respiratory, and partly locomotive. No heart or bloodvessels have been detected in these animals.

Cœlenterata.—These are also destitute of blood, cardiac apparatus, and proper circulatory vessels. In the Actinozoa and Hydrozoa, the digestive cavity communicates with the perivisceral or general cavity of the body, from which ramifications, sometimes very fine and numerous, proceed through the disc and other more developed parts. In this way nutritive fluids get access to all parts of the body, without a circulation of blood.

Protozoa.—The singular, characteristic, slowly pulsating vesicles, which alternately contract and dilate within the soft sarcodous substance of the Infusoria and Rhizopoda, although they sometimes present radiating ramifications, as in certain Infusoria, are probably respiratory rather than circulatory. In the sarcode of the sponges, and in the unicellular Gregarinida, there are not even contractile vesicles; and no trace whatever of internal vessels. The circulation of external fluid through the porous substance of a sponge, has, of course, no affinity to a true internal circulation.

NUTRITION.

The general process by which the microscopic elements of the tissues and organs of the body are maintained in a healthy condition, and are renovated after disintegration and waste in use, constitutes the function of *Nutrition.*

Nutrition proper, consists in the maintenance of a living part, without any important change of form or size. *Growth* implies a more active nutritive process, resulting in an increase of dimensions. *Development*, besides nutrition and growth, requires evolution, or changes of form. *Reparation* is a nutritive act, which has for its object, the healing of a wound or loss of substance, or the more perfect restoration of an injured or lost part. *Reproduction of a lost part*, is an extreme example of reparation. The act of *secretion* is a nutritive process, in which the products of nutrition are incessantly thrown out from the system. The *reproduction of the individual*, is a special nutritive phenomenon.

In Man and the higher animals, the blood is the common source of the nutrient material for the solid parts of the frame, and, in its rapid circulation through the body it passes, whilst in the capillaries, within a very minute distance of the elementary constituents of the various tissues and organs. In yielding this nutrient material, the blood itself is necessarily impoverished, and accordingly is, in its turn, renewed or nourished, chiefly from the lymph and chyle, both of which are likewise constantly being reformed or renewed. All three fluids, the lymph, the chyle, and the blood are, however, more or less organized, or at least, the products of organization. They are, indeed, *fluid tissues* or *fluid parts* of tissues, being the movable contents of vessels or tubes formed by the coalescence of hollow elongated nucleated cells. Like the more solid tissues, they are subject to nutritive waste and renovation. In its widest sense nutrition includes, therefore, the renewal of the lymph and chyle, the renewal of the blood, and the maintenance or renewal of the solid tissues and organs of the body.

In each of these processes there is one common character, viz., that the renewed fluid or solid assumes some portion of a nutrient pabulum, different from itself, and converts it into a likeness of itself. Hence the term *assimilation* is employed, to indicate the assumption of necessary material into itself, by a fluid or solid tissue. The nutrition of the chyle and blood, or the processes of *chylification* and *sanguification*, are especially included under the term *primary assimilation*, whilst the nutrition of the solid tissues and organs from the blood is described as *secondary assimilation.*

Nutrition of the Chyle.

The composition of this fluid, its relations to the food, and the share which the process of absorption has in its formation, have already been described. The nutritive character of that part of the process of chylification, which consists in the absorption of fatty matters, has likewise been indicated. The fatty particles of the chyle within the lacteals, certainly differ from the emulsionized fat found on the surface of the intestinal mucous membrane, and the albuminose of the intestinal canal appears as albumen and fibrin in the chyle. Accordingly, these last-named substances, and perhaps also the fat, undergo true assimilative changes, and not a mere absorption, as they enter the chyliferous vessels. Moreover, the corpuscles which appear, as the fluid advances through the lymphatic plexuses and glands, afford distinct evidence of evolution, organization, and, therefore, of assimilative power. The columnar epithelial cells upon the villi, and also the cells of the absorbent vessels and the alveolar spaces of the lymphatic glands, which are themselves developed by the coalescence of hollow nucleated cells, the parietes of which continue to be endowed with special properties of an elective and, therefore, assimilative nature, participate in this process. If, as previously alluded to (p. 625), the process be regarded as *secernent*, the movable contents of the lacteals form a secretion, and the entire lymphatic system constitutes a large gland, the secreting tubuli of which begin either amidst the tissues of the body, as lymphatic plexuses, or in the villi of the small intestine, as the commencements of the lacteals; whereas the terminal ducts, of which the chief one is the thoracic duct, open into the great veins at the root of the neck. The vascularity of the septa *within* the lymphatic glands, favors the near proximity of the fresh chyle or lymph to the capillary bloodvessels; in this way, these fluids may be inspissated by venous absorption, and, moreover, by the action of the arterial blood, the fibrinous matter may acquire the increase which is noticed beyond the lymphatic glands.

Nutrition of the Blood.

The most obvious evidence of organization in the blood is the existence of its white and red corpuscles. The very special characters of the latter, which are found only in the blood of the Vertebrata, and which, as we shall see, undergo evolution and decay, afford proof of a further assimilative action than that which takes place in the formation of the lymph and chyle. The blood, however, owes the maintenance of its extremely composite nature to other processes than to those of a self-assimilative character: viz., to its losses in the nutrition of the solid tissues of the body, and in the formation of the various secretions; to the changes which it incessantly undergoes, by the entrance into it of new matter, by venous absorption on the one hand, and to the passage from it of effete matter, by excretion on the other; and lastly, to the profound alterations in its character, effected by the action of oxygen in the respiratory process. For these reasons, the subject of the formation of the blood, or Sanguification, will be more conveniently considered hereafter.

Nutrition of the Organs and Tissues.

The nutrition of the various solid parts of the body, *nutrition proper*, or *secondary assimilation*, consists of the following steps or stages.

First, a *nutritive fluid* or *plasma* exudes from the blood, through the coats of the capillaries, into all the interstices of the tissues. This process may be partly due to porous diffusion under the influence of the pressure of the blood in the bloodvessels, but partly also to a dialytic movement, regulated by the chemical relations between the liquor sanguinis and the walls of the capillary vessels. As these vessels are everywhere developed in the same manner, from coalesced nucleated cells, the structure, chemical composition, and properties of their walls are probably the same in every tissue and organ. Hence we may infer that the nature of the exuded fluid plasma, is the same in every part of the body, and, accordingly, that a uniform material derived from the blood, is provided for the nutrition of every part of the system. This nutritive plasma is sometimes supposed to be identical with the liquor sanguinis; but this is doubtful. Fluids effused into various parts of the body, when present in sufficient quantity to be examined, are found to undergo coagulation after they are removed from the influence of the living tissues; they therefore contain a certain quantity of fibrin or fibrinogen, and so far resemble the liquor sanguinis; but they appear generally to possess less albumen and saline matter. Moreover, the liquor sanguinis contains all the ingredients of the blood, whether nutritive or effete, excepting the white and red corpuscles; whilst it is more probable that the exuded plasma, destined for the nutrition of the tissues, consists of a purer nutrient material. Whatever its precise nature, the exuded plasma passes into the finest interstices of the vascular tissues, between the capillary networks, and bathes all the elementary parts of those tissues. Moreover, it penetrates, beyond the vascular parts, all the moist non-vascular tissues, such as the cartilages, the cornea, the capsule and the substance of the crystalline lens, and, likewise, probably even reaches the intervals between the cells of epithelial and epidermoid tissues. The essential difference between a vascular and a non-vascular tissue, consists in the relative distance of their microscopic elements from the nearest capillary vessels, and, therefore, in the space through which the plasma has to pass from those vessels before it penetrates the tissue. All the tissues, indeed, whether vascular or non-vascular, whether penetrated by capillaries or not, are, strictly speaking, *extra-vascular*, that is to say, their elementary parts are outside the walls of the corpuscles. The existence of serous or white vessels smaller than, but continuous with, the capillaries, is not generally admitted; but in certain tissues, secondary nutritive channels may exist, as, for example the lacunæ and canaliculi of bone, and the tubuli of the dentine, by aid of which the nutritive fluid may be still further distributed. The tubular structure of the connective tissue corpuscles and their processes, and the connection of these with the lymphatics, are not admitted.

The *second* stage of the nutritive process consists in the exercise of a certain selective act, or so-called elective affinity, by the elementary parts of the tissues and organs, by which they assimilate to themselves such portions of the nutritive fluid as are suitable, either without or with further change, to renew, molecule by molecule, their disintegrating substance. The nucleated cells of the epidermis and epithelium, the corpuscles of the gray matter of the brain, the tubular fibres of the white nervous tissues, the complex fibres of the striated muscles, the simple fibrous forms of the contractile fibres or fibre-cells of the organic muscular tissue, and of the fibrous and areolar tissues, and lastly, the consolidated intercellular substance, with the remnants of cells embedded in it, as in cartilage and bone, each derives from the exuded plasma of the blood, and assimilates, its required chemical constituents. The more rapid the waste, the more active is the renovation, both processes being most marked in the muscular and nervous tissues, which produce and regulate all animal movement. This assimilative power of the tissue elements is the persistent, primitive, nutritive force, inherited from the germ-cell. It is probably alike possessed by every cell, however remote in its descent from the parent cell, and however modified, so as to form parts of a composite animal or tissue, just as it undoubtedly is when a single cell constitutes the entire animal. This germ force, or germinal force, is the essential cause of all nutritive phenomena, as it is of all organization, whether animal or vegetable. By it, the cellular yeast plant grows and maintains itself in fermenting saccharine solutions, the larger fungi feed themselves upon juices derived from decaying organic matter in the soil, the various tissues of the more complex flowering plants are formed and supported out of a common pabulum, the sap; and, in the Animal Kingdom, the unicellular Gregarina, the sarcodous Rhizopod, the proteiform Amœba, the soft-bodied Cœlenterata, with their ectoderm, endoderm, and intermediate tissue, and, lastly, all the complex tissues and various organs of animals higher in the scale, and of Man, are duly nourished.

By this, the nerve tissue attracts from the plasma outside the capillaries its essential fatty and other constituents, the muscular fibre assumes the materials for fresh syntonin, the cartilage those for its chondrin, the bones their peculiar animal and earthy materials, and so on of every other tissue of the body. The act of nutritive assimilation is said to imply a *metabolic* effort, operating in regard to the substance of the tissues, whilst in development or evolution, this is associated with a *metamorphic* effort, which determines their form. Both kinds of nutritive phenomena are manifest chiefly, probably exclusively, in certain *areas* around the nuclei, or corpuscles, of the cells, the so-called *germinal centres*, which are therefore known as areas and centres of nutrition. The few cases in which, as in elastic ligaments, the nuclei or corpuscles are said to be absorbed, may only be apparent exceptions to the rule. Certain conditions of the blood, and of the temperature of the body, are essential to the occurrence of nutritive actions. They are most active at the commencement of the life of any animal, and gradually decline, as that advances, until the power to maintain the body is overcome by the forces which lead to its degeneration and decay.

In reference to the act of assimilation, and, indeed, of original organization, it is remarked by Graham, that colloidal substances may not only be regarded as forming the essential plastic elements of the body, capable, like all colloids, of existing both in the liquid and in the pectous condition; but that, in the organizing and assimilating process, these colloidal bodies do pass from the liquid into the pectous state, as they assume the form and characters of tissues and organs. The slow rate of these colloidal changes harmonizes with the gradual and periodic nature of the processes of growth and disintegration, with which all vital phenomena, whether of vegetative or animal life, are connected. The ENERGIA, or force, peculiar to colloids, may be, indeed, the primary source of the physical force appearing in the phenomena of vitality (Graham).

Thirdly, the result of the act of assimilation by the various tissues, is to leave a residual fluid in the interspaces of the tissue-elements, outside the capillary vessels. The nature of this interstitial fluid, unlike the common plasma, of which it is a residue, must differ in the different tissues, as, for example, in muscle, brain, liver, and connective tisssue. This residual portion of the nutritive plasma not being effete, but merely defective in composition, is supposed to enter the commencing lymphatics, and thus to be returned to the blood through the absorbent system. Probably, as already indicated, this is accomplished by true assimilative acts on the part of the lymphatic vessels and glands, owing to which certain appropriate constituents, only, of the residual portion of the plasma enter the commencing lymphatics. It is remarkable that these vessels are most abundant in the connective tissue, in which the residual part of the plasma is least altered, and few or absent in muscle and brain, where the greatest modifications are effected in it, and where, accordingly, it is less fitted to form fresh lymph. It might be conceived, without adopting Virchow's and Recklinghauser's views as to the origin of the lymphatics in the connective tissue corpuscles, that the areolar tissue in, and between, all the organs of the body, acts as a sort of spongy bed or matrix, into which the residual part of the nutritive plasma escapes, and so may be more easily taken up by the lymphatics which abound in it.

Fourthly, the final residue of the exuded plasma, which is neither used by the tissues of the body, nor absorbed by the intruded lymphatic vessels, remains to be accounted for. This must be conveyed, probably, by simple and unavoidable dialysis, without power of selection or rejection, into the venous half of the capillary network, and the minute venules immediately adjoining. No other destination can be assigned to it, and unless it were carried off, dropsical accumulations or effusions would take place in the tissues. From this it would appear, that whilst the still serviceable parts of the residual plasma, left after the nutrition of the other tissues, are restored indirectly to the blood, by lymphatic absorption and assimilation, the unserviceable or final, and no longer nutritious residuum, passes into the circulation directly, by means of venous absorption.

Lastly, with this final residuum of the nutritive plasma, there are necessarily mingled the products of the disintegration of the tissues, which always accompanies their action. Without waste there is no use, and without use there is no life. It is the loss which living and acting tissues undergo, which necessitates their nutrition; and whilst new pabulum is brought by the arterial blood, which yields a nutritive plasma through the walls of the arterial half of the capillary network, from which plasma all the tissues receive respectively their requisite materials, the products of their waste would seem first to become dissolved in the ultimate residuum of the plasma, and with it, to enter the venous blood through the walls of the venous half of the capillaries and of the minute veins. These products of waste are really effete, and no longer fit for the purposes of nutrition; physiologically, they are the result of a process of *de-nutrition*, and, chemically considered, of a process of *oxidation* of the tissue substance. It is these which impart to the blood its *positive* venous characters. Thus, venous blood is more watery; it contains less nutritive matter; it is also rendered impure by containing the waste products of the tissues, the chief of which are carbonic acid, lactic acid, and urea. The former of these, as we shall hereafter see, is replaced by oxygen in the lungs, and so a negative defect in venous blood, the want of that stimulating agent is supplied. Here, also, the carbonic acid is given off; whilst the lactic acid, phosphates, and urea are eliminated, or cast out of the blood by the excretory glands, especially by the skin and kidneys.

The five stages of the nutritive process, though here separately described, viz., the exudation of the nutritive plasma from the blood, the assimilation of parts of this by the tissues under repair, the absorption and assimilation of other portions by the lymphatics, and lastly, the re-absorption of the final residue, together with that of the waste products of the tissues, by the venous capillaries and veins, are, of course, in the living body, simultaneously and continuously performed, and in the healthy condition, with a perfect balance of action. Especially must the removal of the waste products be incessant, or they would taint the nutritive plasma, and cause inflammation, as in reality occurs in rheumatism and gout.

In the embryo, and in the growing animal, nutrition not only repairs the constant waste of the tissues, but, as already stated, contributes to the formation of new morphological elements, in the processes of development and growth. But, after the body has attained its maturity, growth ceases in most, though not in all of the tissues. Hence *two* kinds of nutritive processes are noticeable in the adult.

In *one*, not only are the already existing cell-elements, and their secondary intra- or intercellular products, supplied with materials for their special nutrition, until they have passed through all the metamorphoses peculiar to them; but new cell-elements or germinal centres, are constantly being reproduced and developed, for the purpose of supplying the place of those which are cast off; these new cells, are, in turn, succeeded by others. This process, named *continuous growth*, occurs in the epidermis, nails, and hair, in the epithelial tissues of the mucous membranes and secreting glands, and probably also in the gray nervous substance. Moreover, from the active internal changes of absorption and deposition constantly going on in bone, as indicated by observations on the bones of animals fed with madder, it would seem that new cells are continually being formed in that tissue, and, if so, perhaps in cartilage also. In the nutrition of the blood, there occurs not merely a continued renovation of pre existing red corpuscles, but also the death and disappearance of a certain proportion of these, together with the reproduction of new ones. In the *other* mode of nutrition, when once a tissue has attained maturity, no new morphological elements are added to it; such is supposed to be the case with the areolar and fibrous tissues, and with the muscular and nervous fibres. In these tissues the nutritive process consists merely in interstitial disintegration and deposition, affecting the elements of the perfectly formed tissue, molecule by molecule, so as effectually to preserve the shape and size of a part or organ, as long as the normal or healthy standard of nutrition is maintained. According to this view, even the enlargement of a muscle from exercise, is owing to an increase in the size of the fibrillæ in each fibre, and not to the formation of new fibres, or even of new fibrillæ; whilst muscular emaciation is due merely to a diminution in the size of those elements. It is, however, supposed by some, that, as in bone, so in muscle, new centres of growth or nuclei are developed from time to time, and give rise to new fibres, amongst the pre-existing ones, some of which are, on the other hand, constantly undergoing retrograde changes, and disappearing.

In the mode of nutrition by the continuous growth of new cells on the surface, the old elements are cast off directly at the surface of the body, or of some one of its internal membranes; parts of them, however, are sometimes reabsorbed as secretions. In the interstitial mode of nutrition, the products of disintegration, arising from nutritive changes in the substance of the tissue, are taken up, if not by the absorbents, at all events by the bloodvessels, and so enter the blood.

The phenomena of nutrition are necessarily affected through the blood, by the quantity and quality of the food, by all the changes which occur in the blood itself, by what is called the general condition of the health, by exercise or the reverse, and by external conditions, such as temperature, mechanical causes, pressure or violence, or chemical agents.

Nutrition is also affected, and modified, by the state of the nervous system, as exemplified by the effect of emotions and other causes, probably in the main through the action of the vasi-motor nerves regulating the diameter of the small arteries of a part. Perversions of the condition of the nerves or nervous centres, may induce a perverted state of the nutritive processes, both general and local. The formative and nutritive energy is, however, not derived from the nervous system; for it is manifested not only in animals destitute, so far as is known, of any nervous system, but even in plants. Moreover, it begins to act in the ovum, previous to the existence of a nervous system, which system, indeed, is developed by its agency. Of the numerous instances usually adduced to prove that the nervous system may directly guide, or modify, the nutritive changes in the tissues, independently of its action on the bloodvessels, none are satisfactory, if adduced in the case of animals possessing bloodvessels; for it is impossible, in such cases, to exclude the action of the nerves upon these vessels. But there are animals, low in the scale, such as the Beroe and other Cœlenterata, in which a nervous system exists, without bloodvessels; and, in these cases, any action of the former, upon the nutritive processes, must be direct, and not through the agency of vessels. The increased nutrition or secretion from a part in such an animal, due to a stimulus acting on its nerves, furnishes, unless this is influenced by the contraction of the tissues themselves, the requisite example of such direct action. If so, by analogy, it might also occur in the vascular animals, and in Man.

Certain muscular organs, stimulated through the nerves, such as the gravid uterus of the Mammalia, and the muscles of the frog after the season of hibernation, undergo normal periodic enlargements. In this form of over-nutrition, both the processes first mentioned usually occur, viz., an increase in the size of the pre-existing elements, or *hypertrophy*, and also an increase in their number, or *hyperplasia*. Budge has actually observed this latter mode of increase, in the muscles of the frog, new fibres being developed from nuclei arising from the old ones within the sarcolemma of the pre-existing fibres. In such cases, a corresponding increase takes place in the nerves, and new nerve-fibres also appear to be developed by aid of the nuclei of the old ones. (Kühne.) The bloodvessels of such parts must also enlarge,—a change not due to simple dilatation, but to a coincident interstitial hypertrophy of the tissue-elements of their walls.

Various deviations from the normal standard of nutrition are met with in the body; they are fertile sources of organic disease, giving rise to the morbid conditions known as *hypertrophy* and *hyperplasia*, *neoplasia*, *atrophy*, *softening*, *induration*, *degeneration*, and *inflammation*, with its consequences.

Hypertrophy and *hyperplasia*, already defined, are usually attributed, either to an over-abundance of certain materials in the blood, suitable to the development of some particular tissue, or to excessive supply of blood, to over-exercise of a part, or to some not understood tendency to an increase of size or growth, by excessive enlargement or multiplication of the tissue-elements. Muscular hypertrophy and hyperplasia are more common in the involuntary than in the voluntary muscles.

Neoplasia, or the formation of new growths, is referred to a perverted nutrition. Its cause is unknown; though it is attributed, with some probability, to the accumulation in the blood of some similar nutritive material or pabulum, fitted to stimulate their formation, and support their growth and nutrition. The resulting *tumors* are sometimes *homoplastic* or *homologous*, that is, they exhibit a structure similar to that of some normal tissue; or they are *heterologous* or *heteroplastic*, their structure being entirely unlike any healthy texture. Fatty, fibrous, cartilaginous, and bony tumors belong to the former, and tubercle, fibroplastic sarcomas, and cancers, to the latter variety of new formations. These, when once formed, are the seat of continued nutritive changes, more or less perfect and proper to themselves, and maintaining, in the midst of interstitial changes, the character of the abnormal tissue-elements of each growth.

Atrophy, or the gradual or rapid wasting of a part or tissue, depends on general defective nutritive activity, an unhealthy condition or deficient supply of blood, want of exercise in a part, or loss of intrinsic nutritive power. Atrophy may be general, as that which follows deficiency of food or actual starvation, or partial and local, as that which occurs in the fatty tissue, when no fatty, amylaceous, or saccharine food is eaten, and the blood is destitute of fatty matter.

Softening, *induration*, and *degeneration*, imply not only defective, but more or less altered, nutrition. The first consists in a liquefaction of the tissue-elements; the second and third, in depositions, in or about them, of albuminoid or amyloid substance, or in an actual conversion of the proper albuminoid or gelatin-forming material of the tissue, into fatty matter,—a change not unfrequently seen in muscular tissues, especially in those who indulge in alcoholic beverages. In certain cases, fatty degeneration prepares a tissue, or some morbid deposit, the result of inflammatory or perverted hypertrophic or hyperplastic action, for more easy absorption and removal from the body; sometimes this and other changes destroy tumors, and so lead to exhaustion and death.

Inflammation is essentially an abnormal or altered nutritive process. It commences in some altered relation between the nutritive qualities and reactions of a tissue, and of the blood, or its exuded plasma; the normal nutritive changes are arrested; the unused plasma soon becomes excessive in quantity; new products are stimulated into growth, including, essentially, cells formed by multiplication of the pre-existing connective tissue corpuscles. Moreover, the condition of the blood, and of the capillaries, very soon becomes changed; the blood becomes less fluid, and the vessels distended and enlarged, causing a state of congestion; the red corpuscles of the blood in the part, cohere, and at last become motionless or stagnate, *stasis* being produced; the white corpuscles increase in number in the blood generally, owing, it is supposed, to over-activity of the commencing lymphatics of the inflamed part. Lastly, the nerves of the part are excited by these changes, and by the disturbance in their own nutrition. The chief obvious results and evidences of inflammation are swelling, redness, heat, and pain; but these are effects, and not even essential characters, for one or more of them may be, under certain circumstances, absent.

Inflammation may end favorably in *resolution*, which consists in the absorption of the exuded material, and of the new products stimulated to growth by it. These may, however, undergo rapid increase, and form solid and morbid *plastic deposits*, or fluid *pus*, abounding in corpuscles like the white blood corpuscles, and so give rise to induration, inflammatory thickening, or *suppuration*. Collections of pus, surrounded by plastic deposit, constitute *abscesses;* these, by progressive absorption of their coverings, may reach the surface, and burst. A further result of inflammation is *ulceration*, which consists in the *molecular* death, and gradual softening and falling away, of a highly inflamed part of the surface of a tissue or organ, causing a loss of substance, or sore known as an *ulcer*. *Gangrene* or *mortification*, is the complete *molar* death of a part, dependent, sometimes, on excessive inflammation, causing obstruction or occlusion of the larger or smaller bloodvessels, or an actual destruction by violence, heat, cold, or chemical agents. The body may also be wounded, or parts even completely detached from it.

As inflammation and its consequences are essentially derangements of the nutritive process, so, on the other hand, all the *reparative* phenomena seen in the living animal body, which tend to preserve life, consist in most remarkable and energetic manifestations of modified development, growth, and nutrition. Thus, the cavity of an abscess is chiefly closed by the collapse of its sides; but, also, by a new and very vascular, soft, red formation, in its interior, known as *granulations*, which are developed from new cell-elements, partly metamorphosed into connective tissue, and partly into bloodvessels, whilst certain of the cells escape as pus; ultimately, these granulations cohere, and the orifice being closed up, is covered by new epidermis, or by *cicatrization*. An ulcer, or a wound is filled up, and healed, in a similar manner, by granulation, suppuration, and cicatrization, the resulting mark being named a scar, or cicatrix. The temporary covering or natural dressing of an ulcer, known as a scab, consists of dried exuded materials and pus. Gangrenous parts are detached, separated, and thrown off, by a remarkable ulcerative process, or molecular decay, occurring, not in the dead parts, but in the living parts in immediate proximity to them; when these are detached, the raw surface is healed by granulation, suppuration, and cicatrization.

The *healing* of actual *wounds* differs according to the extent, depth, and relative proximity of the surfaces, and the degree of their exposure to the air. It may sometimes occur by *immediate* or *direct union*, as in the healing of subcutaneous wounds, without any manifest inflammation, and, it is said, even without any observable exudation of intermediate or uniting plastic matter. Sometimes this may also occur in the healing of external cut surfaces, which have quite ceased to bleed, and can be maintained in accurate and immovable apposition, and from between which air can be totally excluded. Most frequently, however, healing is accompanied by more or less inflammatory action and the formation of a new uniting substance; this constitutes union by *adhesive inflammation*, or by the *first intention*. In this mode of union, plastic matter is exuded, new cells are formed and converted into connective and capillary tissue, and so the divided, but apposed surfaces, are joined. When the wound is deep, or the loss of substance is great, or the apposition of the surfaces impossible, or when, from any other cause, the adhesive inflammation does not happen, then the surfaces granulate and suppurate like those of an ulcer or abscess, and when these have closed up the cavity, cicatrization ensues. The extent and mode of reparation in each tissue, and in various animals, will be explained in the Section on Development. In all cicatrices, or other repaired parts, nutritive changes afterwards go on, resulting, as in the healthy tissues, in the maintenance of the form and characters of the newly developed tissue or scar.

Offices of the Blood and of its Several Constituents in Nutrition.

The general fact, already indicated, that the blood is the source of all the nutrient material for the solid tissues of the body, is illustrated in many ways. Thus, the activity of the nutritive process is coincident with the quantity and quality of the blood supplied to a particular part or organ. Unless it be constantly supplied, through the absorbent system, with fresh nutriment from food, it becomes itself impoverished, showing the demand made upon it by the nutritive wants of the solid tissues. Ligature of the arteries of a part is followed by a diminution in its size, owing to defective nutrition; and not only does complete closure of the arteries accomplish this, but even their compression.

There are instances in which an increased supply of blood, through enlargement of the arteries, occurs as a natural phenomenon in the living body, and, in such cases, this *determination of blood*, as it is called, is accompanied by an increased growth in the part or organ supplied, as exemplified in the annual development of the antlers of the stag, and in the periodic enlargement of the mammary glands in the Mammalia, for the supply of their young with milk. Again, the falling of the antlers, and the disappearance of portions of healthy bone, in the ordinary nutrition of that texture, are always preceded or accompanied by a gradual shrinking and final closure of the vessels which nourish them, by the filling up of the Haversian canals of the bony tissue; thus nutrition is arrested, as the supply of blood is cut off. Lastly, hemorrhages or bleedings are followed, eventually, by diminished nutrition of the body. But the immediate effects of severe hemorrhage are most remarkable. The functional activity of the muscular and nervous systems, the exercise of which also demands rapid nutritive changes, is either enfeebled, suspended, or lost. Every sensation, perception, emotion, or volition, and every movement, is accompanied by disintegration of nervous or muscular tissue, or of both; these tissues are maintained in a fit state for action, by a due supply of oxygenated blood and nutritive plasma, and the several changes which occur in them and in the blood, are retrogressive chemical decompositions, accomplished through the agency of the oxygen conveyed in the latter. Accordingly, a loss of blood from hemorrhage, a diminution of that fluid from pressure on the vessels, or an arrest of the circulation from ligature, or other causes, is followed by a diminution, suspension, or annihilation of the functions of a muscle or nervous centre. Similar results ensue from serious alterations in the quality of the blood, as when the proportion of oxygen in it is deficient, or when carbonic acid is in excess, as is seen in the immediate loss of consciousness and muscular power, which follows the arrest of the decarbonizing and oxygenating processes of respiration. The nutrition of the body, generally, also becomes defective, from a continually diminished supply of pure air, owing to the blood not being then duly oxygenated and purified. Finally, the influence of the blood in stimulating and nourishing the tissues, is directly proved by the remarkable resuscitating effects of injecting that fluid into the veins of persons or animals, previously deprived of blood by accidental or intentional hemorrhage, the powers of the whole system which have previously been suspended, being, in this way, almost instantaneously restored.

The nutritive, stimulating, and resuscitating powers of the blood, depend on the chemical constitution of the liquor sanguinis, and on the number, composition, and properties of the corpuscles which it contains; and the special offices of the different parts of this fluid, for the processes of nutrition, may be referred both to its morphological and chemical constituents, which have already been described (pp. 57, 79).

The white corpuscles appear to serve, at all periods after birth, for the renovation of the red or colored ones. They are very abundant in sickly and ill-fed persons; also in anæmia, in inflammations, and in certain diseases of the spleen, probably because they do not then undergo the usual change into red corpuscles, and so relatively accumulate in number.

The *red corpuscles*, by virtue, as it would seem, of the coloring matter, or *cruorin*, are the great carriers into the system of oxygen, which displaces carbonic acid from the blood during respiration, as will be explained in the section on that subject. The substance usually known as hæmatin, is a product of the decomposition of cruorin, by the action of acids or caustic alkalies. The hæmatin of Lecanu is a highly-colored albuminoid substance, containing iron; its chemical relations with the myochrome of muscles, the pigment of the choroid and iris, of the hairs and skin, in both the dark and fair races of mankind, and also with the coloring matters of the bile, the urine, and the suprarenal bodies, may indicate some nutritive relations between it and them; it may, perhaps, be formed in the spleen, or in the lungs, and may be dissolved, in minute quantity, in the nutritive plasma, and so find its way chiefly to the muscles and hairs, in the coloring matter of both of which iron is also found. The red corpuscles also probably furnish, by their solution, continuous supplies of albuminoid matter to the liquor sanguinis, the globulin of the corpuscles having a close resemblance to albumen and syntonin. The fact, however, that the red corpuscles contain most of the potash, whilst the liquor sanguinis contains most of the soda of the blood, may indicate that the muscular tissue, which also abounds in potash, may receive special nourishment from these; and, as they also contain a phosphorized fatty matter, they may have special nutritive relations, direct or indirect, with the nervous substance. The quantity of the red corpuscles in the blood, is certainly greatest in healthy and vigorous persons. These corpuscles are also most abundant in the hot-blooded Birds, not quite so numerous in the Mammalia, the temperature of which is not so high, and much fewer in the cold-blooded Reptiles, Amphibia, and Fishes. Their proportion in the blood is in direct relation, not only with the temperature of the body, but also with the general activity and energy of the muscular and nervous apparatus. From this cause, the ratio of the general solids to the water of the blood, shows similar proportions in the different Vertebrate Classes.

The special nutritive office of the liquor sanguinis, must be explained by its composite chemical constitution. Its peculiar physical character of smooth viscosity, due to the albumen, and particularly, it is said, to the fluid fibrin which it contains, is highly favorable to the easy passage of the blood along minute channels like the capillaries, without its exuding too freely through their walls, and perhaps also to the uniform suspension of the red particles in it. A tendency to exude in undue quantity through the coats of the vessels, is probably favored by a diminution in the amount of fibrin, as well as by like changes in the proportions of the albumen and the salts.

The uses of the particular chemical constituents of the blood as a whole, require further consideration. The *albuminoid* principles of the blood, its most abundant constituents, include the globulin of the red corpuscles, the albumen of the white corpuscles, and that held in solution in the liquor sanguinis; this latter is said to be chiefly derived from, or prepared by, the blood corpuscles, the globulin of which is believed to escape into the liquor sanguinis, either through their thin envelopes, or after their solution. These albuminoid substances are of the highest nutritive value; for they, or their derivatives, are found, in larger or smaller quantity, in all the tissues and organs of the body, both in the microscopic cell-elements and the intercellular substance, appearing as albumen or syntonin in the nervous tissues, as syntonin in the muscles, much changed, as a gelatin- or chondrin-yielding substance in the fibrous and areolar tissues, bone, and cartilage, and as elastin in the yellow ligaments and other elastic tissues. Gelatin is not found in the blood itself; but when digested, it is converted into a gelatin peptone, and so becomes absorbed, as we have seen, but in what state, is not yet known; nor is its destination in the nutritive processes of the body certain. Either it may serve for the direct nutrition of the gelatin-yielding tissues, or, and this is very probable, it may, by itself undergoing oxidation, conserve other more important tissues, and, at the same time, maintain the temperature of the body. Its efficacy as administered in jellies, beef-tea, and broth, in cases of sickness, especially indicates its importance as an article of diet. Furthermore, the albuminoid substances, such as salivin, pepsin, pancreatin, and casein, found in many most important secretions, must be derived from the albumen of the blood. The quantity of these formed in the day is considerable, but those contained in the digestive fluids are quickly absorbed into the blood again. Though so highly nutritive, and absolutely essential to the economy, albumen, considered as an organizable substance, has no metamorphic power; though it affords a fit material for metamorphic action.

The *fibrin* of the blood was formerly supposed to be specially intended for the nutrition of the muscles, their albuminoid constituent, syntonin, being considered to be identical with the fibrin of the blood. It is now believed that the fibrin is not so essential for nutritive purposes as the albumen, and the small proportionate quantity in the blood, as compared with other albuminoid bodies, viz., about 1 to 90, is in accordance with this idea. Fibrin is more highly oxidated, or contains more oxygen, than albumen; hence it may be a degraded form or condition of albumen, exhibiting a retrogressive change into some still lower compounds. As already mentioned, it may assist in maintaining some essential physical characters of the blood; and, lastly, it plays a highly important part, in causing the coagulation of this fluid. To this change in the blood, the character and causes of which will be hereafter discussed, the first closure of the orifices of bleeding arteries and veins is often due, and further hemorrhage is thus arrested. Moreover, in most acts, especially in the union of divided parts, and in the healing of sores, the fibrin contained in the exuded plasma coagulates, forming the first bond of union, and a matrix in which nuclei or nucleated cells are developed; further reparative changes then ensue, according to the tissue which is the seat of reparation. But the coagulation of exuded fibrin in the living animal economy, though often beneficial, sometimes induces injurious consequences to the system, as, for example, in adhesive inflammation of the peritoneum, by which the intestines and other organs become adherent, or constricted by bands of newly-formed tissue, which interfere with, or altogether hinder, their proper movements and actions; in similar adhesions between the lungs and the side of the chest, between the heart and the pericardium, and also, and still more strikingly, in the attachment of the iris to the capsule of the lens, or other parts within the eyeball, even causing blindness by the complete closure of the pupil. Not only fibrinous exudations from the vessels, but even extravasated blood itself, may coagulate within the tissues; by some, it is maintained that it may itself become the seat of subsequent organization.

The *fatty matter* of the blood, which is of various kinds, is highly nutritive, scarcely any tissue being altogether destitute of fat in larger or smaller quantity. Phosphorized fats especially abound in the nervous substance, and exist in the red corpuscles of the blood. Fat is always present in newly-forming tissues and newly-forming cells, the nuclei of which often contain fatty particles surrounded by an albuminous deposit. Fatty matter is found, too, not only in the fluid parts of the blood, but also in the organized morphological elements, the blood corpuscles, especially in the red ones. It was observed by Ascherson, that when oleaginous substances are agitated with albuminous solutions, the fatty matter breaks up into minute particles, surrounded by a film of albumen; and he believed that some such physical combination of oleaginous and albuminous matter, might explain the formation of the lowest morphological elements, such as granules, and even of certain nuclei, though not the origin and growth of cells themselves. Without adopting this view, it may be admitted that fatty matter is essential to all nuclear and cell growth, and to every process of tissue formation, even to the assimilation of albuminous matter; for fat-globules are always present in the ovum or germ-cell of every animal. Fat is necessary to the formation of certain secretions, as of the bile, milk, and sebaceous matters of the skin. The bile contains a very large quantity of fatty acids. It is possible that fat itself may be derived from other constituents, as from albuminoid, amyloid, or saccharine matter. The great value of oleoids, especially of such as are easily digested, absorbed, and assimilated, is exemplified in the beneficial action of cod-liver oil in tuberculous diseases. Besides its use as a nutritive substance, the fat of the blood is probably also constantly subject to oxidation, for the production of animal energy and heat. But there are other substances in the blood, which are probably even more easily oxidated than its fats.

Arterial blood does not contain any *amyloid* substance; but traces of *sugar* are present in it. This is formed in the liver, but also, it would seem, in the muscles, and probably in other parts; it is also taken up from the food. Nevertheless, the quantity present is small; it is, perhaps, less concerned in nutrition than in the production of heat and motion by its rapid oxidation. It may, however, take part in the formation of milk. The inosite, lactic acid, creatin, and creatinin, and other extractives, are probably not so much directly nutritive, as stimulating, or excretive; they all represent stages of chemical retrogression, from less to more oxidized compounds, and may, by their further oxidation, assist in the evolution of heat. As completely effete and non-nutritious, or even poisonous, must be classed the urea, detectable, in minute traces, in the blood, as well as the ammonia which escapes from it when it is drawn, and the uric acid, all of which are excretory substances.

The *salts* of the blood are said to prevent its decomposition, and also to regulate its chemical characters and its specific gravity or density, so as to adapt it to the healthy condition of the liquor sanguinis and blood corpuscles floating in it. It is well known that certain salts are preservative, and, likewise, that if the blood corpuscles be suspended in a fluid of too low a specific gravity, they immediately become distended, a process of endosmosis going on into them; whereas, if the fluid be of too high a specific gravity, they shrink by exosmosis. But neither of these supposed uses, explains the great variety of the saline constituents of the blood; for one saline substance alone, say common salt, would have sufficed for both these purposes. Several uses are probably served by this variety. Thus, some salts, perhaps, are necessary for the maintenance of the properties of blood; others are destined for the nutrition of certain tissues, or the formation of certain secretions; whilst others again appear to be the result of the disintegrating and oxidating processes going on in the tissues and organs of the body, during the exercise of their respective functions.

Thus, *common salt* or *chloride of sodium*, appears to be present in the blood of all animals, and in every tissue. Its great importance is evidenced by the tenacity with which it is held in the bodies of animals, and accumulates in their blood and tissues, even when, as in the cases of the herbivorous species, the food which they consume, contains comparatively minute traces of it. The strong necessity and appetite for salt, felt by the herbivorous Mammalia, is shown by their licking lumps of that substance, or boiled bones, scattered about their pastures; and also by the periodical migrations of herds of cattle to the salt districts in South America,—facts which indicate that salt is indispensable for the healthy condition of the blood, and of the tissues which are nourished from it. It would seem, indeed, that chloride of sodium is associated with every important act of tissue formation and change. Of the secretions, all exhibit minute traces of salt; but the gastric juice in particular, contains an acid—the hydrochloric—derivable only from the salt of the blood; for the quantity of chloride of potassium, as compared with the chloride of sodium, in the blood, is so small, that it may be inferred that the latter is the source of this acid of the gastric juice. The large quantity of soda present in the bile, in combination with its fatty acids, is probably also derived from the common salt in the blood; the separation of the chlorine from this, for the formation of the hydrochloric acid of the gastric juice, may be accompanied by the transference of the sodium, in the shape of soda, to the hepatic cells, for combination with the biliary acids. Again, the lime salts in the blood, chiefly the phosphate of lime with carbonate, held in solution in lactic and carbonic acids, are highly important nutritive substances, being found in all growing tissues; as is well known, they are especially deposited, as a consolidating material essential to the formation of the skeleton, and of the dentine and enamel of the teeth. Of these tissues, although the enamel undergoes no nutritive change after it has been formed, and the dentine very little, the bones are constantly exhibiting very active metamorphoses. Carbonate of lime, phosphate of magnesia, and silicates and fluorides, are usually associated with the phosphate of lime.

But there are other salts, such as the *phosphates* and *sulphates*, both of potash and soda, which, probably, are derived from the oxidation of the phosphorus and sulphur contained in the phosphorized fatty matters found in the red corpuscles, and especially in the nervous tissues, and in the sulphuretted albuminoid substances existing in muscle and brain. The phosphorus and sulphur in these compounds, are either directly oxidized and combined with soda or potash, or else they pass first into intermediate substances, such as the highly sulphuretted substance, the taurin of the bile. If carbonates of soda or potash exist in the blood, they also are probably not nutrient, but represent the results of chemical retrogressive metamorphoses in the blood and tissues. Moreover, the phosphate of soda, which has an alkaline reaction, and any carbonate of soda which may be present in the blood, serve very important and special uses in that fluid, helping to dissolve the albumen, to favor the chemical oxidation of many substances in the blood, the absorption of gases, and the passage of the nutrient plasma through the walls of the capillaries. The salts of potash are, it would seem, absolutely necessary to the nutritive changes which occur in muscular tissue. The importance of potash especially, in preserving the healthy condition of the blood, perhaps by determining or aiding the chemical actions necessary for that end, is illustrated in the beneficial effects of fresh vegetables and fruits, as articles of food. They especially abound in neutral or acid salts of potash; and a diet from which they are absent, if long used, induces that condition of the blood, which causes scurvy or *scorbutus*. The employment of neutral salts of potash, aids, at least, in the cure of this disease; but it is more effectually remedied by the use of lime-juice, potatoes, or fresh vegetables themselves. Hence, perhaps, a vegetable diet operates on the blood and tissues, in some other mode than by the potash in which it abounds.

Of the *gases* contained in the blood, the nitrogen is probably indifferent, and without special office, its relative proportion constantly varying, both in arterial and venous blood. On the other hand, the *oxygen* must be regarded as an agent of the highest importance. It purifies the blood, and, dissolved in, or combined with, the cruorin of the red corpuscles, is by them carried through the system, and operates on all the tissues. Its action is not so much to contribute to the formation of tissue, by being combined with, or *fixed* in, the tissues in the act of morphosis, as to stimulate the tissue elements, especially those of the nervous and muscular tissues, to their proper functions, causing chemical changes or oxidations of their substance, or of the blood passing through them, essential to their action, and more or less destructive of their substance. So essential is oxygen for this purpose, that the deprivation of it, for but a few minutes, is fatal to the life of these two tissues. As to the *carbonic acid* gas of the blood, not only is it neither nutrient nor stimulant, but it is the chief ultimate product of the oxidation of the tissues, being probably derived, however, from the oxidation of intermediate compounds, into which the materials of the used-up blood and tissues break down. It is the ultimate effete form in which most of the decomposed carbonaceous substances are eliminated from the body. It is an impurity in the blood, which requires to be incessantly expelled from it. and, indeed, is so displaced by the aid of the oxygen in respiration. Under its influence, the scarlet color and the other properties of arterial blood are changed, and the blood becomes dark and venous. It is so detrimental to the life of both the nervous and muscular tissues, that, in cases of asphyxia, in which it ceases to be eliminated by the lungs, death seems rather to take place from the poisonous nature of the accumulated carbonic acid, than from the mere absence of the nutritive, or stimulating and vivifying, oxygen.

The nutritive properties of the blood *differ* according to many circumstances, being influenced by the character of that fluid, the age, sex, temperament, habits as to exercise and occupation, the constitutional state, and the nature of the food. Thus arterial blood is more nutritive and stimulating than venous blood, which will not long support life, especially that of the nervo-muscular apparatus. Arterial blood not only contains more oxygen, and less carbonic acid, but its liquor sanguinis is richer in fibrin, and its corpuscles contain more cruorin and saline substances, and much less fat—their total solid matter being less than that of the corpuscles in venous blood. The fluid part of arterial blood also contains less fat, but more saccharine and extractive matters. Again, the blood is less rich in childhood than before birth; its corpuscles increase, however, at puberty, but, after fifty years of age, again diminish. The blood is richer in solid contents, especially in red corpuscles, in men than in women; the same is true of plethoric and sanguine persons, as compared with those of lymphatic or serous constitution. The quantity of the fatty matter is more influenced by the diet, than that of the other organic proximate constituents. Exercise in the open air purifies and oxygenates the blood. This fluid is, of course, profoundly modified in disease.

Hemorrhage or Loss of Blood.

The escape of blood from its vessels into the surrounding tissues is named *extravasation;* if into one of the cavities of the body, or externally, it is named *hemorrhage.* The loss of from four to six pounds of blood, from one or more of the great vessels, will generally prove fatal to an adult; but if the hemorrhage be slower, much larger quantities may be drawn from the bloodvessels, without a directly fatal issue. Death from sudden hemorrhage is caused by the want of sufficient blood to supply the nervous centres, so that fatal *syncope*, *i. e.*, fainting, takes place; when death occurs from prolonged hemorrhage, it is not from a defective supply of nutriment to the tissues generally, but from a slow exhaustion of the nervous and muscular power, affecting the brain, spinal cord, and heart, due to a deficient supply of nutriment and of oxygen to them, in consequence of the diminution in the number of the red corpuscles.

Every one should be acquainted with the various forms of accidental hemorrhage, and their impromptu treatment. If it be *general oozing* from small vessels, which is easily recognized, and if it proceed from a part to which pressure can be applied, a handkerchief closely folded into the form of a pad, and firmly bound over the spot by another handkerchief, will generally suffice to stanch the bleeding for a time; the part should then be kept elevated and at rest. In hemorrhage from a *vein*, the blood is dark, and the stream flows continuously, welling up over the surface. Moreover, pressure with the finger on the side of the wound further *from* the heart, will almost entirely arrest the bleeding; whilst if pressure be applied on the side of the wound *next to* the heart, the flow of blood becomes more copious. To arrest venous hemorrhage, a small thick pad should be applied upon the wound, so as to extend a little to the side further from the heart; this should be firmly secured by a handkerchief or bandage; the chief pressure must be made on the side of the wound away from the heart, because that is the direction from which the blood flows. *Arterial* hemorrhage is known by the blood being bright, and projected in a jet from the wound, sometimes to a considerable distance, usually by jerks, though, if the artery be very small, there are merely slight intermissions in the force of the jet, and, in wounds of very minute arteries, the jet is continuous. Moreover, pressure on the side of the wound further from the heart has no effect on the stream; but pressure on the side nearer the heart, stops it. To arrest arterial hemorrhage from a small artery, therefore, a pad of suitable size should be applied upon the wound, and extend also on the side *next* to the heart; it must be, not merely firmly, but *tightly* bound by a handkerchief or suitable bandage. If the artery be large and deep seated, very forcible pressure becomes necessary, and in order to communicate this specially to the artery itself, a small thick and unyielding kind of pad is necessary. This should be made, not by folding a handkerchief, but by rolling it up as tightly as possible, with or without some firm substance inclosed within it. Beneath the handkerchief used as a bandage, a short stick may be inserted on the side of the limb opposite to the wound, and then be twisted round, so as to increase the pressure.

These directions apply to veins and arteries situated in the limbs. Upon the head, simple pressure with the thumb or finger, will suffice to stop bleeding from either kind of vessel, because the bones of the cranium afford a perfect means of counter-pressure. Wounds of the large vessels of the neck, require very special management; but, as a general rule, direct pressure with a pad, maintained in its place by the thumb, is the best means to have recourse to, until proper assistance, by forceps and ligature, can be afforded.

In cases of sudden and great loss of blood, living blood, drawn from the veins of another person, has been injected into the veins of those suffering from the hemorrhage. This is known as the *transfusion of blood*. Two hundred years ago, Lower (1665) suggested this operation, having found that animals, apparently dead from hemorrhage, were quickly revived, when blood, taken from another animal, was immediately injected into the veins. As an operation upon the human subject, transfusion was perfected by Dr. Blundell. The blood received into a warmed funnel connected with a proper syringe, is immediately transferred to the veins of the patient, no time being permitted for the occurrence of coagulation. The records of fifteen cases of the saving of life by this operation, have been collected by Béclard. In experiments on animals, it is better to defibrinate the blood, so as to prevent coagulation; the process of whipping the blood, also, to a certain extent, oxygenates the blood. It has been supposed that the fibrin itself is injurious, but the better oxygenation of the beaten defibrinated blood may account for its apparent superiority. Arterial blood has been shown to have a greater restorative or stimulating effect, than venous. The serum of the blood is useless for the purposes of transfusion. Water has also no effect, unless it be used warm; it is useful when the blood is loaded with carbonic acid, as in asphyxia, or cold and already thick or tarry, owing to loss of water, as in cholera. Solutions of common salt, or of salts selected so as to imitate those of the blood, yield surprising, but only temporary, restorative results. The blood of one Mammalian species may be injected, with impunity, into the veins of another species; and, contrary to what was formerly supposed, blood possessing oval red corpuscles, such as the blood of Birds, does not prove fatal when injected into the veins of Mammals, in which the red corpuscles are circular, provided the injected blood be arterial, and not venous, nor previously agitated with carbonic acid. (Bischoff.) Blood taken from a starving animal is highly injurious, if injected into the veins of another, causing peculiar symptoms, apparently referrible to the effects of decayed or decomposed animal matter. (Bernard.) Hence the animal, or person, subjected to transfusion-experiment, or operation, should be in good health, and recently well fed; for then, not only will the loss of blood be better supported, but the blood itself will be newly derived from the food; moreover, owing to the more watery character of the chyle, as compared with the blood, the fibrin in the latter will be diluted, and any injurious influence which this substance might produce will be diminished.

The accidental injection of *air* with the blood into the veins, has probably been the cause of the fatal results in some transfusion experiments. Air so injected, or introduced by wounds of the veins in the neck, when it reaches the heart, is speedily fatal, either by mechanically interfering with the functions of the valves, or by chemically failing to excite contraction, like pure blood; or it may induce coagulation, or obstruct the pulmonary capillaries, after it has been driven with the blood, in the state of froth, through the pulmonary arteries.

Vitality of the Blood.

The blood, as it exists in the vessels of a living animal, is not a mere physical and chemical mixture of certain substances adapted to the nutritive wants of the rest of the body; but, with or without the inclosing capillaries, it is an organized fluid tissue, possessing *vitality* like the solid tissues. Its corpuscles are evolved and disintegrated like the other structural elements of the body. As we shall hereafter see, these bodies are originally developed simultaneously with the earliest vessels of the embryo, and the loss to which they are subject during life, is repaired by corpuscles newly formed in the system. The physiological endowments of these corpuscles, especially of the red ones, are quite peculiar, and are as characteristic as those of any of the structural elements of the solid tissues. With regard to the liquor sanguinis, in which the corpuscles float, it also has vitality, and must be regarded as the liquid, intercellular or internuclear, matrix of a fluid tissue; for it is originally elaborated with the corpuscles, in the interior of conjoined nucleated cells. The vitality of the liquor sanguinis is probably, however, like that of the intra- or inter-cellular parts of the solid tissues, dependent upon its corpuscles, gymnoplasts, or nuclei, which are its real centres of growth; just as the semifluid nervous substance, the somewhat firmer sarcous elements, the areolar fibres, and the yet denser matrix of cartilage, or the solid deposit of osseous tissue, appear to be dependent upon the nuclei proper to those tissues respectively.

The vitality of the blood is merely a *vegetative life*, its inherent vital properties being strictly nutritive, and including neither contractility nor sensibility. The fluidity of the liquor sanguinis is an indispensable condition to the life of the whole body, and such vitality as it or the corpuscles possess, must be constantly exercised in the maintenance of that condition. So, reciprocally, the persistence of the vital properties of the blood implies, within certain limits, the maintenance of its peculiar fluid state and chemical constitution. Yet, as we shall immediately see, the remarkable change which takes place in one constituent of the liquor sanguinis—viz., in the *fibrinogen*, or *fibrin*, which, when blood is drawn from the body, solidifies into delicate fibrils, and, entangling the corpuscles, gives rise to the phenomenon known as the *coagulation* of the blood—is, by many eminent physiologists, regarded as a vital act.

The Coagulation of the Blood.

This phenomenon, already elsewhere noticed (p. 60), does not consist of a solidification of all the elements of the blood, but of that of the fibrin alone, of which, on an average, not above 3 parts exist in 1000 of blood. The effects of this change in so small a quantity of fibrin, are very remarkable. A few minutes after blood is drawn from a vein or artery, it appears to set, or stiffen, into a red jelly-like mass or *clot;* from the surface of this, yellowish transparent drops of fluid very soon exude, which then run together in little pools; the red mass slowly shrinks, forces more and more of the transparent fluid from it, becomes more and more solid, and, at the end of from twenty-four to forty-eight hours, constitutes a clot equal in bulk to about one-third of the total volume of the blood, the rest now consisting of the yellow fluid, which is named the *serum.* This serum contains most of the water, besides the albumen, salts, and extractives of the blood; whilst the clot, coagulum, or crassamentum, is composed of the fibrin, together with the red and white corpuscles. The clot still contains, however, some serum, and, in order to remove this, it is necessary to lift it from that fluid, cut it in pieces, and drain it upon a proper filter.

The composition of the clot and serum may be inferred from the facts stated in p. 79. When portions of the clot are examined under the microscope, the solidified fibrin is seen in the form of exceedingly minute fibrillæ, not more than the $\frac{1}{30000}$th or $\frac{1}{50000}$th of an inch in diameter, nearly straight, subdividing dichotomously, and sometimes assuming the appearance of rows of minute particles. These fibrillæ are most perfect when the blood coagulates slowly. The red corpuscles in the clot are no longer separate from each other, so as to be freely mobile, as in the circulating blood, but have run together in adherent masses or columns, which have been compared to overlapping rows or piles of coins; the white corpuscles are also entangled, but not in groups, though, under certain circumstances, they collect more abundantly in the upper part of the clot.

As freshly drawn blood coagulates, it gives off a vapor known as the *halitus* of the blood. A minute quantity of ammonia escaping in this halitus, is also evolved. (Richardson.) No carbonic acid escapes, as was once supposed. An *odor*, often characteristic in the case of different animals, is likewise perceptible, not so much during the coagulation of the blood, as before that event takes place, when the blood is hottest. During coagulation, no heat is evolved, the temperature of the blood, indeed, being already lowered, more or less, before this phenomenon begins.

The coagulation of the blood is influenced by many circumstances, which determine its rapidity, and modify the characters of the clot itself, as to form, color, and consistence.

The external conditions which *accelerate* the formation of the clot, are rest, or, on the contrary, very active stirring, moderate increase of heat, exposure of the blood to air, its slow escape from an artery or vein, its reception into shallow vessels, and contact with rough or multiplied surfaces, or with foreign solid bodies, and, in certain cases, its slight dilution with water. Within the body the circumstances which favor the coagulation of the blood, are certain enfeebled states of the system, frequent bleedings, laceration of the vessels from which the blood escapes, inflammation of the coats of the vessels, or of the lining membrane of the heart, and so-called atheromatous, or other deposits, upon the vessels or upon the valves.

On the other hand, coagulation is *retarded*, or interrupted, by movement, cold, heat beyond a certain temperature, the exclusion of air, as by covering the blood with a stratum of oil, its rapid escape from a vein or artery, its reception into deep vessels, its contact with smooth surfaces, its exemption from the intrusion of foreign solid bodies, and also by the addition of strong solutions of neutral alkaline salts, or of minute quantities of ammonia. Moreover, it is retarded by the admixture of certain vegetable substances containing narcotic and sedative alkaloids, such as opium, hyoscyamus, belladonna, aconite, and digitalis, and even by strong infusions of tea and coffee. In the case of the addition of strong solutions of neutral salts, and of many other substances, subsequent dilution of the mixed blood, by adding water to it, is followed by a feeble coagulation. The internal conditions which retard coagulation, are certain inflammatory states of the system, perfect smoothness of the interior of the heart and bloodvessels, and, above all, a healthy condition of their lining membrane.

Although *rest*, as when drawn blood is set aside, is favorable to coagulation, and moderate agitation, as when the blood is gently shaken, in a bottle, delays this act, it is remarkable that *stirring* blood rapidly with a rod, or *whipping* it with a bundle of sticks or wires, causes the fibrin quickly to coagulate in thready masses on the rod; this is the usual method of defibrinating blood, which afterwards remains fluid, or forms but a very soft imperfect second coagulum. The effect of whipping depends on the rapid and frequent contact of the multiplied surfaces of the wires with the blood. Again, a *temperature* varying from 100°, or the natural temperature of the blood, up to 120°, accelerates coagulation, but a greater heat retards it; at 150° this property of the fibrin is said to be permanently destroyed, whilst, above that temperature, the albumen of the blood itself coagulates. When blood is allowed to cool, its coagulation is retarded in proportion to the degree of cold to which it is subjected; at 27½°, or 4½° below the freezing-point of water, it solidifies; and if it has not been previously allowed to coagulate, and the freezing process is rapidly completed, it will coagulate on being thawed. The coagulating property is, therefore, proportionally, sooner destroyed by an elevation than by a lowering of the temperature of the blood; moreover, frozen blood may be preserved for a long time, and yet retain its power of coagulating when thawed. The influence of *exposure to air*, in accelerating the coagulation of the blood, probably explains the corresponding effects of the slow escape of the blood from the vessels, and of its reception into shallow basins. These conditions do not act by lowering the temperature, for that would retard coagulation, nor by the escape of the halitus merely; but it has been suggested that they operate by favoring the escape of ammonia from the blood. All conditions which facilitate the *escape of vapor* or gas from the blood, certainly favor its coagulation. Thus, coagulation occurs in a vacuum, a fact which shows that the presence of air is not necessary, a condition too which would favor the escape of ammonia; but it also occurs, and even more quickly, when the blood is subjected to increased atmospheric pressure. Complete exclusion from air, though it retards, does not prevent coagulation, as blood will at last coagulate in closed vessels, and even within the dead body shut up from the air. The rapid escape of blood from its vessels, and its reception into deep glasses or basins, are supposed to retard coagulation, by affording less opportunity of exposure of the blood to the air. Of all the circumstances which hasten the formation of the clot, the multiplication of the points of *contact* with solid bodies seems to be the most potent; the smallest particle of thread suffices to induce rapid coagulation, where, in the absence of any foreign body, a much slower process of clotting would have occurred. Blood received into metal or earthenware utensils, is said to coagulate sooner than when received into glass vessels, perhaps owing to difference of roughness of the surface. The accelerating effect of slight *dilution* and the retarding influence of the addition of *saline solutions*, are not well explained; they may operate, simply by altering the specific gravity, and also the viscosity of the blood. The retardation, or prevention, of coagulation, by the addition of *ammonia*, even if transmitted through the blood in the form of vapor, the occurrence of coagulation in such blood when the ammonia escapes, and its resumption of the fluid state on the introduction of fresh ammoniacal vapor—phenomena which can be reproduced several times over, in the same blood—are the chief facts adduced, together with the known presence of ammonia in the halitus of the blood, in favor of the hypothesis of Dr. Richardson, that the ammonia is the cause of the fluidity of the blood in the body, and its escape, the immediate occasion of coagulation in drawn blood.

The mode of action of narcotic and sedative *poisons*, is not understood. The more rapid coagulation of the blood in feeble *states of the system*, does not depend upon an increased quantity of the fibrin or coagulating substance, but rather on the dilute or watery condition of the blood. On the other hand, the more slowly coagulating blood of the inflammatory state is accompanied by an actual increase in the quantity of fibrin, though there appears, possibly from the high specific gravity and richness of the blood, to be a greater resistance to the act of coagulation. The necessity for perfect *smoothness* of the interior of the heart and bloodvessels, in order to prevent coagulation, may be inferred from the highly polished character of their epithelial lining; the influence of rough surfaces in their interior, in determining coagulation of the blood, is shown by the small coagula formed upon excrescences of the valves of the heart, and by the flakes of fibrin which collect on atheromatous or calcified portions of vessels in the rough interior of aneurisms, and at the openings of lacerated vessels, which are so much sooner closed by coagula, than those which are cleanly cut. Coagula have been induced experimentally in animals, in the interior of large vessels, by the passage of needles, wires, or threads, into such vessels; when formed in an artery, the coagulum is firm and elongated in the direction of the blood current, whilst, in the veins, the clots are loose and massive. In certain cases, during life, especially during the last hours of life, such coagula may form in the living blood, especially when rough excrescences exist on the valves of the heart. The influence of an *inflamed* condition of the *coats* of the bloodvessels, in causing coagulation of the fibrin, has been referred to the partial loss of vitality, or to the interruption of the vital processes, in the inflamed tissue, by which it is, so far, approximated to the state of inanimate matter. The injection of pus, the pulpy substance of the brain, and other semisolid matters, into the bloodvessels of an animal, rapidly coagulates the blood, a result probably attributable to the effects of contact with the multiplied surfaces of non-living matter.

Blood confined in a living vein between two ligatures, retains its fluidity for a long time, beginning to coagulate commonly after from 3 to 5 hours, and sometimes even being only imperfectly clotted at the end of 24 hours, though such blood will coagulate in a few minutes when withdrawn from the living vein. If the vein be dead, although the blood is equally well excluded from the air, coagulation takes place within a quarter of an hour. Experience shows that blood may be retained in occluded vessels, and yet continue fluid for a considerable time, or that blood may be extravasated in the midst of the living tissues, and yet preserve its fluidity for many days, though it will soon coagulate when afterwards withdrawn from the body. From these and other facts, it has been inferred that the *living tissues* possess some special property, by which they maintain, or preserve, the fluidity of the blood; according to one view they actively prevent its coagulation; according to another, they operate negatively, by not determining that process, as dead matter would, whether it were an inorganic solid, or a dead animal substance, such as brain-substance, dead muscle, or pus. The poisons and the modes of death, which influence the coagulation of the blood, for the most part retard or prevent it. Sudden destruction of the substance of the brain or spinal cord in an animal, causes coagulation of the blood even in the living vessels, in which clots are found after a few minutes. The poison of venomous serpents appears altogether to destroy the coagulating property of the blood; narcotic poisons, and prussic acid have the same effect; asphyxia or suffocation, whether from hanging, drowning, or the action of gases unfit to support respiration, also cause the blood to remain fluid after death. In cases of death by lightning, by electric shocks, by blows on the epigastrium, or after a severe chase, the blood has been said not to undergo coagulation; but this seems to be untrue, the blood being often, though not always, found fluid, but after a time undergoing coagulation. In cholera, the coagulation is also postponed.

The *form*, *consistence*, *and color of the clot*, exhibit many varieties. From *healthy* blood, the clot is flat or slightly concave on the upper surface, especially if the blood has been received in a shallow basin, when the clot is soft, and very little serum exudes from it. When an upright vessel is used, the surface of the clot is a little more concave. The consistence of a healthy clot is firm and uniform; its color is bright red on the top, from exposure to the air, but dark in its lower portions. In *inflammatory* diseases, especially in pneumonia or inflammation of the lungs, the blood is very rich in fibrin, containing, instead of 3, above 5, often 7, and even as many as 13 parts in 1000; nevertheless it coagulates slowly, and the coagulum presents a remarkable peculiarity known as the *buffy coat.* Such a coagulum shrinks more than usual, is exceedingly firm, and very concave on its upper surface, forming what is called the "*cup*," which presents a thick layer of a nearly coloress, yellowish, or greenish-yellow hue, the so-called *buff* or *buffy coat.* This coat, and the cupped form are more marked when the blood is received into a narrow and deep basin, than into a shallow one; in the former case, the coagulation is slower, and in the latter quicker, as with healthy blood. The buffy coat is very firm and tough, and, when examined under the microscope, is found to consist of fibrillated fibrin, intermixed with many white corpuscles; from some cause, the red corpuscles partly subside before the commencement of coagulation, and so escape being entangled in the upper portion of the clot. It was formerly supposed that the slower rate of coagulation of inflammatory blood, accounted for this subsidence of the red corpuscles from the upper strata of the fluid, before coagulation took place; and this view is supported by the fact that the corpuscles, which are heavier than the liquor sanguinis, do subside in blood, the coagulation of which is intentionally retarded by the addition of strong solutions of sulphate of soda or of common salt. But other circumstances probably co-operate to increase the tendency of the corpuscles to settle down. The disposition of the red corpuscles to run together in columns and masses, in blood drawn from the body and left at rest, is increased in the inflammatory state, the corpuscles then running into larger clusters, clinging more firmly together, and even losing their circular form, and becoming elongated. The aggregation of the corpuscles into larger masses, perhaps causes them to subside more rapidly than if they adhered in the usual minute piles or columns; and this, together with the retardation of the coagulating process, may account for the formation of the buffy coat. This unusual aggregation of the corpuscles also occurs in certain low constitutional states, and, it is said, in plethora; it likewise happens, when the coagulation of the blood is retarded intentionally in experiments. A tendency of the corpuscles to fall to the lower part of a living vein inclosed by ligatures, has been seen in animals. The nature and cause of this tendency of the corpuscles to run together, remains, however, yet unexplained. Their apparent mutual attraction is diminished by the addition of weak saline solutions, and the buffy coat, if the blood be inflammatory, is less distinctly developed, although the period of coagulation is delayed. The addition of any material, which, like mucilage, increases the aggregation of the corpuscles, accelerates the subsidence of the corpuscles, and increases the buffy coat.

Contrasting with the firm, fibrinous, and contracted clot of the blood in inflammation, are the loose, soft coagula, characteristic of the blood of weak, cachectic, and anæmic persons, even though the clot is formed more rapidly. A deficiency of fibrin causes the clot to be soft. During bleeding, the power of coagulation of the blood is gradually modified as the blood flows, the last quantity drawn setting more rapidly, but forming a softer clot. Fragile, almost semifluid clots are found in the blood of those who have died of cholera, from strokes of lightning, or from asphyxia.

That the immediate cause of the coagulation of the blood is the solidification of the fluid fibrin of the liquor sanguinis, is shown by the existence of the fibrinous fibrillæ, in clotted, but not in fluid blood; by the formation of the buffy coat without any admixture of the red corpuscles, the upper and firmest part of this coat being nearly pure fibrin; and lastly, by the fact that whipping the blood, which removes the fibrin, prevents any further coagulation, the corpuscles themselves not possessing this power, then remaining free and suspended, or subsiding in the serum, which is likewise no longer coagulable. Experiments also demonstrate this property of the fibrin. Thus, if the coagulation of the blood be retarded by the addition of solutions of neutral salts, the red and white corpuscles have time to subside, and the upper clear fluid, which still contains its fibrin, then undergoes coagulation, the delicate colorless clot exhibiting the characteristic microscopic fibrillæ. Again, by adding a solution of salt, or of sugar, to a quantity of frog's blood, the corpuscles of which are very large, the fluid part of the blood, or liquor sanguinis, may be actually filtered from the corpuscles, and will afterwards undergo coagulation.

The cause of the solidification of the fibrin has been the subject of much speculation and difference of opinion, and is still not satisfactorily understood.

Many living physiologists, agreeing with Harvey, Hunter, and others, maintain, as already stated, that the coagulation of the blood is a manifestation of vital power in that fluid. Harvey said of the blood, that it was the *primum vivens* and the *ultimum moriens* of the body; whilst Hunter considered the coagulation of the blood as its last act of life. An analogy has been drawn, somewhat vaguely, between the solidification of the fibrin of the blood and muscular contraction, and, perhaps, with more justice, between it and the rigor mortis, or rigidity of the muscular tissue after death. Several modern authorities perceive in the fibrillation of the solidifying fibrin, the evidence of an organizing plastic process, the feeble efforts of a formative vital energy. Moreover, it is urged that effusions, undoubtedly fibrinous, upon the surfaces of serous membranes, in the interior of the eyeball, between the ends of tendons or other cut surfaces divided subcutaneously, and in other situations, become organized and vascular, and are converted into a low form of areolar or fibrous tissue; and that not merely fibrin, but even blood clots in the interior of vessels, as in cases of ligature of arteries, or blood extravasated in the midst of the tissues, may also become, under certain circumstances, vascularized, and converted into a definite tissue, in the same way as inflammatory fibrinous exudations are, the blood corpuscles not assisting in the process, but rather delaying it. (Hunter, Zwicky, Paget, Hewett.)

Notwithstanding the support given to the idea of the coagulation of the blood being a vital act, and of the possession of a vital property of solidification by the fibrin of that fluid, it may be doubted whether this doctrine is correct. There is no real analogy between muscular contractility, which requires peculiarities of structure, and complex statical and dynamical electric conditions, and the simple change of the fibrin of the blood from a fluid to a solid state. If its comparison with the rigor mortis be more exact, the tendency of modern opinion is to regard this phenomenon not as a vital act, but truly as a *rigidity of death*, dependent on chemical changes then ensuing. Again, there is no true resemblance between the minute fibrillæ of solidified fibrin and any fibrous or other tissue of the body; the former are homogeneous, the latter, indeed, always present differences of parts. Fibrinous deposits or effusions may become the seat of positive organization, so as ultimately to give rise to a tissue; but then nuclei, or centres of growth, arranged in methodical order, and even cells, appear within it, for the formation of the future tissue elements and the new capillary vessels; these nuclei and cells are supposed to have their origin, not in the fibrin, but from the corresponding parts of the surrounding tissues. In cases of so-called organization of the coagula formed in ligatured arteries, in the interior of inflamed veins, or in other situations amidst the living tissues, it is the surface of the clots next in contact with those living tissues, which first presents appearances of organization and vascularization. This suggests the possibility that, subsequently to the effusion of blood, a true plastic exudation may take place around the clot, and may penetrate between the columns of its aggregated corpuscles; in this way, the apparent organization and vascularization of a clot may, ultimately, be the same process as that of a fibrinous effusion, depending on formative acts on the part of the surrounding cell elements, which give rise to nuclei, cells, or intercellular substance. According to this view, the coagulum of the blood constitutes a sort of nidus for future developmental processes, but is not itself converted into tissue. The fibrillæ of the coagulated fibrin may support the effused mass, divide it into areolæ or spaces, and thus favor the penetration of exuded plastic matter, and the penetration of nuclear growths through it. The plastic lymph, though a fibrinous material, may not be identical with the solidified fibrin of the blood, but may be a true protoplasm, more distinctly and positively possessed of organizable tendencies, and thus of a real though low form of nutritive life. If this be so, the strongest argument in favor of the vital character of the coagulation of the fibrin of the blood is nullified.

Moreover, many facts appear irreconcilable with such a doctrine. Thus, the blood of a horse has been kept in a fluid state, by means of nitre, for fifty-seven weeks, and yet speedily coagulated, when sufficiently diluted with water. (Gulliver.) Frozen blood, as already stated, will coagulate when thawed. If, therefore, coagulation is a vital act, the life of the blood must be admitted to be capable of being "pickled" and "frozen." (Gulliver.) It is replied by the vitalists, that the vitality of the fibrin is simply preserved in a dormant condition, by the prevention of spontaneous change or decomposition; just as the dormant vitality of seeds and ova endures for years, and as that of infusorial animalcules, and even of the highly organized Rotifera, may be restored, after considerable elevation or lowering of the temperature, or may be suspended, and so conserved by desiccation. But the recovery of animalcules after freezing is, probably, only apparent, a minute drop of surrounding unfrozen water perhaps, defending them from actual congelation; whilst in blood thoroughly frozen, the fibrinous fibrillæ, undergoing no nutritive changes, could hardly escape that event. Furthermore, there is no example of the recovery of life, by any of those minute organized beings, after immersion in so potent a substance as a solution of nitre, which is a well-known solvent of fresh fibrin.

On the supposition that the coagulation of the fibrin is not a vital, but a *physical* process, it has been maintained that the fibrin is held in a fluid state in the living blood, by a minute quantity of ammonia, and that the escape of this ammonia is the immediate cause of its coagulation—at least when blood is drawn from the body. The celebrated Robert Boyle (1684) considered that the blood gave out a spirit, and observed that it could be maintained in a fluid state by a salt of ammonia, and that clotting occurred after the removal of this. It was proved by Haller that the halitus of the blood is alkaline. Albumen, it is known, is rendered soluble by the fixed alkali, soda, but may be precipitated by the addition of an acid. Lastly, it has been shown by Richardson, that ammonia is really given off from blood, microscopic crystals of hydrochlorate of ammonia being formed on a piece of glass moistened with a trace of hydrochloric acid, and held over freshly-drawn blood; also that, by the transmission of the ammoniacal vapor from fresh blood, through other fresh blood, the latter may be kept fluid for an unusual time; that air containing the vapor of ammonia has the same effect, and will, even after coagulation has taken place, restore the condition of fluidity—the clotted and fluid conditions being alternately producible, according as the ammoniacal vapor is passed into the blood, or is permitted to escape from it. The minute proportion of 1 part of ammonia to 3000 of blood, is sufficient to maintain the fluidity of the latter. Finally, nearly all the conditions which appear to favor or accelerate the coagulation of freshly-drawn blood, are such as would also facilitate the escape of the volatile alkali from it (Richardson).

Other considerations and facts appear, however, to show that the escape of the ammonia from the blood, which undoubtedly occurs, is not the cause of the solidification of the fibrin, but merely an accompaniment of that change. In the liquefaction of solid fibrin by ammonia, and its alternate re-coagulation and liquefaction by the subsequent subtraction and addition of ammonia, it is not certain whether the fibrin of these secondary and tertiary solidifications is identical with the fibrin of the primary clot. Many experiments and observations further show that freshly-drawn blood may be placed in such conditions that its ammonia cannot well escape, and yet coagulation will occur; *e.g.*, when blood is received into a bottle which is quickly stoppered, or when blood rendered fluid by ammonia coagulates, though tardily, if kept in air-tight vessels (Zimmerman); or, again, when blood, subjected to increased barometric pressure, which would check or prevent the escape of ammonia, is found to coagulate even quicker than usual (Colin). Moreover, blood drawn from an animal, and exposed to the air for fifteen minutes, at a temperature of 32°, even though its ammonia had probably escaped, has been found to remain fluid for upwards of five hours, when introduced into the freshly removed heart (Brücke). The blood in a dead body is usually found coagulated in the heart and the larger arteries and veins, but fluid in the smaller vessels, although ammonia could apparently escape or transude more easily from the latter. This coagulation in the heart and larger vessels, is partly due to post-mortem changes, but, sometimes at least, the clots begin to form during the last moments of life. Again, blood confined between two ligatures in a living vein, retains its fluidity for many hours; but if a piece of glass-tube be introduced between the blood and the walls of the vein, coagulation very speedily occurs (Brücke). So, too, when needles, wires, or threads are passed through living vessels, the blood will coagulate in the vessels, though the ammonia could not, by any possibility, escape from the moving blood (Simon and Lister). The coagula thus formed in veins, are large, soft, and dark; whilst those formed in pierced arteries are small, compact, and pale. In both kinds of vessels the broadest or attached part, or base of the clot, is directed towards the heart. No escape of ammonia can take place when a clot forms in a ligatured artery, nor in that coagulation of the blood during life, which occurs from the sudden destruction, in animals, of the substance of the nervous centres. Nor can this explain the coagulation produced by the injection of dead brain-substance, or of pus, into the blood, nor the fact that blood inclosed between two ligatures in a dead vein speedily coagulates; whilst blood similarly inclosed in a living vein remains fluid, the facility for the escape of ammonia being apparently, in either case, the same (Astley Cooper, Brücke, Lister).

Indeed, this last-mentioned experiment, added to the well-known circumstances, that blood, extravasated amidst the *living* healthy tissues, remains for a long time fluid, whilst if in contact with inflamed vessels or tissues deficient in vitality, or with the lining membrane of vessels containing morbid deposits, or with dead animal substances out of the body, it quickly coagulates, indicates a striking contrast between the effect of contact of living and dead animal tissues on the blood, the former, in some way, retarding or antagonizing the coagulation of that fluid, the latter, in some way, accelerating or determining it (Lister).

[At a recent meeting of the British Association for the Advancement of Science, Dr. Richardson publicly withdrew his theory of coagulation of the blood, stating that further research had shown him there were such strong physical objections to it as a theory, that it was no longer tenable. Dr. Richardson also illustrated his present views on the subject of coagulation, with special relation to the causes of the phenomenon. Some recent experiments of his own on the influence of extremes of heat and cold on albuminous and fibrinous fluids, have shown him that the process of coagulation in these fluids is due to a communication of caloric force to them, and to a physical or molecular change, determined by the condition of their constituent water. Thus all substances which possess the power of holding blood in the fluid condition, such as fixed alkalies, various soluble salts, and volatile alkali, in every respect act after the manner of cold, rendering latent so much heat, in the absence of which the fibrin remains fluid. In the opposite sense, every substance which combines with water, and produces condensation, with liberation, quickens coagulation. In other words, according to Dr. Richardson's present views, coagulation is facilitated by heat and retarded by cold.

He also stated that in the ordinary condition there is a constant process, similar to coagulation, going on in the living body, in the formation or construction of muscle, and a steady and persistent interchange of force from those parts which are solidified by cold and fluidified by heat, to those which are rendered solid by heat. He concluded by stating that the process of *rigor mortis* was an illustration of the same order of phenomena. (*Am. Jour. Med. Sci.*, Jan., 1868, p. 245.) F. G. S.]

It has been suggested that the immediate cause of the coagulation of the fibrin, may have some relation to the distinction between the crystalloid and the colloid condition of matter. (Graham.) Fibrin, like all albuminoid bodies, is a colloid substance; and one of the properties of these, is a proneness to molecular, or molar metastases, by which they pass, not only from a pectous to a liquid, but also from a liquid to a pectous state (p. 607). Albumen undergoes this latter change, on the application of heat; casein, on the addition of acid pepsin, or of an acid with heat, and fibrin, still more readily than either, becoming, when left to itself, solidified at moderate temperatures, and more rapidly, at somewhat higher temperatures. The coagulation of fibrin not being due to any external apparent cause, has been designated *spontaneous*. But this more ready assumption by fibrin, of the pectous condition, can hardly be spontaneous, in the usual sense of that term; unless, indeed, we suppose the vital endowments of this remarkable substance to be higher even than Hunter believed. Crystallization is as much spontaneous in one sense as coagulation. The latter probably depends upon some definite molecular or molar changes, strictly physical, like any other less rapid effect of colloidal energy, and occurring when the fluid fibrin is removed from the ordinary influence of processes going on in the living vessels and tissues within the body, or when it is subjected to other influences exerted upon it by the dead tissues, or by foreign bodies generally.

The action of these latter may be *catalytic*, or due to contact, and the fact that rough or multiplied surfaces accelerate coagulation, favors this view. It has been suggested that dead matter may induce a reaction between the solid and fluid constituents of the blood, in which the former, that is the corpuscles, impart to the fibrin of the liquor sanguinis a disposition to coagulate. When, however, no foreign substance is introduced into the blood, the catalytic action has been supposed to be due to the corpuscles themselves, which, as it were, ceasing to undergo their characteristic vital changes, and so, in effect, becoming dead, determine, like other dead animal matter, the solidification of the fibrin. (Lister.) The influence of the red corpuscles in producing or accelerating coagulation is well established; the upper colorless stratum of either inflammatory or diluted blood, in which the corpuscles have subsided, coagulates more slowly than the lower part, in which the corpuscles are present. (Gulliver.) Chyle, to which a minute portion of blood is added, will coagulate in two or three minutes, though the same, when pure, takes from twenty-five to ninety minutes to coagulate. (Schmidt.) The fluids of ascites, pleurisy, and pericarditis, that of blisters, and of other so-called serous exudations, readily coagulate after the addition of a minute quantity of blood, even, it is said, of a few red corpuscles; whilst other portions of those fluids, kept apart, do not. The same effect is produced, however, on the admixture of two such fluid exudations. Fragments of the crystalline lens, the composition of which resembles, or is identical with, the globulin of the red blood corpuscles, and even the crystals of hæmato-globulin obtained from those corpuscles, also induce the formation of a coagulum in these fluids. Hence Schmidt, to whom these latter observations are chiefly due, believes that, within the blood cells, there exists a *fibrino-plastic* substance, and in the liquor sanguinis a *fibrino-genous* substance, and that by the escape of the former and its union with the latter, the act of solidification is effected. But, since dead animal tissues of all kinds, and even clots, or solidified fibrin itself, either fresh, or dried and powdered, produces the same effect, it may be that the action of the corpuscles, in causing coagulation of the fibrin, is not a vital process; and that if, as supposed, their contained globulin escapes, by exosmosis, through their envelopes, into the liquor sanguinis, this is, in reality, a post-mortem event.

Finally, therefore, it is submitted that, out of the body, the solidification of the fibrin, which is the sole cause of the coagulation of *drawn blood*, is due to a mere *physical*, molecular, or molar change, resulting in its transformation from a liquid to a pectous state, as is common to colloidal bodies; that this change is permitted, after the life of the blood, or the incessant nutritive mutations which occur in living blood, cease; that it is accelerated, or induced, by the contact of dead matter, either proper or extraneous, to that fluid, and that it is to be regarded, not as a token of life, but as a sign of death. When coagulation occurs within the body, it is still under conditions indicative of the diminution or cessation of the ordinary vital interchanges of the blood, and so may be equally regarded as a physical process, or, at least, as one of those examples in which the essential cause is physical, though sometimes it may be utilized, and directed to certain formative ends. Lastly, if this view be maintained, the fibrinous fibrillæ of clots formed in the living bloodvessels, or extravasated amongst the tissues, cannot be supposed themselves to be converted, any more than the red corpuscles, into organized tissue elements; but, by their trabecular arrangement, they may facilitate the penetration into such clots, of an organizable blastema, with nuclei or nucleated gymnoplastic cells, and intercellular substance, for the production of newly formed tissue.

The formation of an external clot at the mouth of a wounded or divided vessel, is the first step taken by nature, in the effort to close the vessel; to this, succeeds the formation of an internal clot, the base of which, in a divided vessel, corresponds with the wound, the apex extending towards the heart, as far as the nearest branch of any size. From the divided edge of the vessel, a nutritive plasma, or blastema, is poured out, in which nuclei and nucleated cells, probably derived from the surrounding cell elements, appear, and form the future areolar tissue, with its capillary network, which closes the aperture in the vessel. In the case of a completely divided artery, the muscular coat of the vessel contracts, and retracts within the sheath, and so helps its closure: a lacerated or twisted artery retracts even more securely than one cut cleanly across. When an artery is tied, as in surgical operations, its middle and internal coats are cut through by the thread, whilst the outer one is inclosed in the knot; the two former tunics contract, and turn in towards the area of the vessel, and it is upon their cut edges that the primary clot first forms, and from them, that the new tissue, which closes the vessel, is produced; the constricted part of the outer coat sloughs, and permits the ligature to come away. The artery is closed, and shrinks up to the nearest branch, the primary clot being absorbed: the collateral vessels are greatly increased in diameter, to carry on the circulation beyond the point of ligature. Pressure, by aid of a needle passed through the soft parts upon the side of a divided artery of moderate size, enables its cut end to close: this is now sometimes employed after operations, and is known as *acupressure*. (Simpson and others.)

SANGUIFICATION.

The occurrence of this process in the economy of the higher animals and of Man, is implied in the proper expression of *making blood.* The corpuscles, both red and white, waste, or become worn out, from the nutritive changes which occur in the solid tissues, and in the blood itself. Their number, especially that of the red ones, certainly increases with a high rate of living, and materially diminishes from hemorrhage, starvation, or disease. This waste, and loss of number in the corpuscles, must be repaired.

The *white corpuscles* are supposed to be derived from the lymph and chyle corpuscles which enter the blood, and are identical with its white corpuscles, in size, form, structure, and chemical composition. The large number of white corpuscles found in the blood, three or four hours after complete digestion, their greater abundance in the veins than in the arteries, and especially in the left innominate vein as compared with other veins in the body, are facts which favor this view. No other ordinary source for the production of the white corpuscles of the blood has been suggested, although it has been supposed that, under certain circumstances, as in local inflammation or excitement, they might possibly arise within the capillaries, by subdivision and growth of the nuclei in the walls of those vessels, and then, becoming detached, be moved on with the blood. Some may also arise within the spleen.

The mode of formation of the blood corpuscles, both white and colored, in the *embryo* and its membranes, is peculiar, and will be described in the Section on Development. *After birth*, the *red corpuscles*, it is generally believed, are developed from the white ones, however these latter may arise. Many transitional forms have been traced in the blood. In the progress of change in the Mammal, as described by some (Funke, Paget, Kölliker), the contents of the white corpuscle become more fluid and homogeneous, the compound nucleus disappears, the surface becomes smooth, the size diminished, the shape flattened, disc-like and then biconcave, an exceedingly thin envelope forms around them, and they acquire a red color in their interior. According to others (Wharton Jones, Busk, Huxley), this is true, as regards the nucleated colored corpuscles of Birds, Reptiles, Amphibia, and Fishes; but in the Mammalian non-nucleated colored corpuscle, it is the nuclear portion, only, of the white corpuscle which is converted, by the necessary changes, into a red corpuscle. By some, it is thought that the smaller white corpuscles, or the larger ones after subdivision, undergo this transformation by flattening, disappearance of the nucleus, and acquisition of cruorin; others regard the smaller pale bodies, often described in the blood, as if they were wasting, not growing, red corpuscles.

In the Oviparous Vertebrata, therefore, the red-blooded corpuscle is a transformed pale corpuscle; but in the Viviparous mammalia, including Man, the red corpuscle is the homologue of the nucleus only of the Oviparous blood corpuscle. In both cases, the pale corpuscle is perhaps a naked cell or gymnoplast; but a distinct, though delicate, envelope or cell-wall afterwards appears. The difference between them appears to be, that in the Mammalian red corpuscle the envelope touches the nucleus, around which there are no cell-contents, or the nucleus disappears in these; whilst in the other Vertebrata, the envelope is at a distance from the nucleus, the cell-contents being abundant. The importance of the nucleus, as a centre of activity, is thus well illustrated.

The *chemical changes* in the corpuscles are no less remarkable than those which affect their form. Their globulin acquires phosphorus and iron, the former element associated with fat, and the latter with the coloring matter or cruorin. They now also manifest a singular affinity for oxygen. It is not quite certain in what part of the circulation the change of white into red corpuscles takes place; but it is supposed that this is *completed* during the passage of the venous blood, in which the white corpuscles abound, through the capillaries of the lungs; they are fewer in the arterial blood. The remarkable effects of the respiratory process on the blood, and the strong affinity of the red corpuscles themselves, when fully formed, for oxygen, prove that the oxygenation of the blood, which takes place in the lungs, is accompanied by changes of deep importance in its corpuscles, and favor the idea that it may even be concerned in the conversion of the white corpuscles into red ones.

It has been already stated that the red corpuscles, after enduring or living a certain time, waste or die. Many writers have supposed that they accumulate in the spleen, becoming impacted, as it were, in the venous sinuses of that organ, and then shrinking and disappearing. By others, again, it is believed that the cruorin, or red coloring matter, is added to the young corpuscles in this organ, perhaps even from the *débris* of these red corpuscles, which become stagnated and disintegrated in it.

Besides the corpuscles, however, the intercellular fluid matrix of the blood, or *liquor sanguinis*, is, as we have seen, constantly undergoing loss, in supplying the materials necessary for the maintenance and formation of the great variety of tissues and secretions. Every act of nutrition, like those of secretion, must remove something from, and so far impoverish, the blood. The albumen of the liquor sanguinis is constantly replenished from that of the lymph and chyle, and, by venous absorption, from the digested food; but it may also contain certain more highly elaborated albuminoid materials, derived from the corpuscles. Some of the substances employed in nutrition, such as the salts and earthy matters, may belong properly to, and proceed from, the liquor sanguinis itself; so also may certain albuminoid matters. But others may merely traverse that fluid, on their way from the blood corpuscles, in which they are finally completed, to the tissues, escaping through the envelopes of the corpuscles, by dialysis or exosmosis, passing across the liquor sanguinis, by liquid diffusion, and then permeating the capillary walls, by dialytic or porous diffusion; so likewise of the fatty matters, which must be immediately added to the blood from the nutrient chyle. Some substances, of a more special kind, may be formed by changes in the corpuscles, and may afterwards traverse the liquor sanguinis to reach the tissues. The elaborative office of the corpuscles, and their influence on the composition and formation of the liquor sanguinis, are undoubted.

The fibrin of the blood is believed to be derived from the albumen, of which it is said to be a modified, degraded, or more oxidized condition. It has been stated that, on passing a galvanic current through a solution of albumen, a concretion of a substance resembling fibrin becomes attached to the positive pole (Smee); but this deposit may not be identical with fibrin.

The blood of the hepatic and renal veins contains only a small quantity of fibrin, and coagulates but imperfectly; hence it has been conjectured that fibrin may be destroyed, or oxidized, in the liver and kidneys. On the other hand, the blood of the splenic vein contains much fibrin, coagulates very firmly, and, even when defibrinated by whipping, will produce a second clot, after long exposure to the air. It is thought also, by some, that the action of the muscles may give rise to an appearance of fibrin in the blood; for on injecting defibrinated blood into the arteries of a recently detached animal's limb, the blood returning by the veins is found to contain fibrin, whenever the muscles have been excited to repeated contractions by galvanism.

The amyloid and saccharine matters are probably added to the blood chiefly from the liver, the inosite from the muscles. The nitrogenous creatin and creatinin are probably products of the decomposition of albuminoid matter. The coloring matter is possibly, in part, newly formed in the lungs; but previously existing cruorin may perhaps be used again.

The nutritive changes, whether of waste or renovation, in the homogeneous or formless liquor sanguinis, added to those which take place in the organized elements or blood corpuscles, imply a more special, and more complicated, nutritive movement than that which occurs in any *one* of the tissues or glands; for they reciprocate with the metamorphoses of *all* the tissues and glands. The variety of nutritive and secernent changes to which the blood ministers, and in which it itself undergoes incessant corresponding alterations, is very great, and yet its highly complex, but essential, constitution remains, within certain limits, the same.

The constitution of the blood is also continually changed, on the one hand, by the accumulation within it, of its own effete materials, and its reception of those of the disintegrated solid tissues, and, on the other, by its constantly casting out of itself the various products of that decay. In this way, its creatin, creatinin, and urea, and its lactic and carbonic acids, enter, and then escape through the agency of the renal, cutaneous, and respiratory excretions. The quantities of effete extractives and of urea are small, for they are always being carried off; if they accumulate, mischief ensues. Considering that the blood is constantly drawn upon for the supply of nutriment to the rest of the body, that it is intermittently and variously renewed, that it is itself subject to decay in its essential structural and fluid elements, and the seat of constant additions and subtractions, its composition retains a remarkable unity. The complexity of the mutual relations between the blood and the tissues and glands, its renovation from the lymph and chyle, and the rapidity of its purification from the poisonous or injurious chemical products of the disintegration of tissue, by the excretory processes, are very surprising. When imperfectly elaborated, or purified, by the formative, nutritive, and secretory or excretory processes, it becomes unhealthy, and a possible source of disease. Emotional and other disturbances of the nervous centres may, through their influence over these processes, also render the blood unhealthy or even poisonous. General disorder ensues, and the functions, especially those of the liver, alimentary mucous membranes, kidneys, skin, and mammary glands, are vitiated. Cutaneous and other local diseases arise. Further, the blood may become the vehicle of miasmatic and malarious poisons, or the seat of zymotic decompositions, and so fevers, simple, exanthematous, intermittent or remittent, typhoid or choleraic, may ensue.

THE BLOOD GLANDS.

In Nutrition, certain materials are attracted to, and assimilated by the tissues, from the common nutrient plasma of the blood, and the materials so attracted, are removed from the blood. In the act of secretion, as for example, in that of saliva and bile by the salivary glands and the liver, various other materials are separated from the blood. Nutrition and secretion are, indeed, intimately allied, the former being a secretive process, and the latter a nutritive process; hence nutrition is sometimes termed nutrient secretion. Diminished or increased activity or arrest of the nutritive processes in certain tissues, such as the nervous or muscular systems, may affect the blood quite as seriously as errors in the secreting processes; and the healthy balance of both functions is necessary for the preservation of the normal constitution of the blood.

All secreting glands, however, possess special channels, called *ducts*, which open either upon the exterior of the body, as in the case of the cutaneous and mammary glands, or into some internal cavity, as, *e. g.*, the salivary and gastric glands, and by which the materials separated from the blood are conveyed away, though some of them may be more or less completely reabsorbed. But in the nutrition of tissues, such as muscle or nerve, the materials separated from the blood are not carried away by ducts, but remain, for a time, as part of the body, and are only reabsorbed when they have performed their proper functions, and, in doing so, have undergone further change.

Now, there exist in the Vertebrata generally, and in Man, certain peculiar organs, which, from their compact form, general appearance and relations, and highly vascular character, have been called *glands;* but they have no secreting orifices, channels, or ducts proceeding from them, to open on the surface, or into the cavities, of the body. These organs include the spleen, the supra-renal bodies, the anterior portion of the pituitary body, the thyroid body, and the thymus. From being destitute of ducts, they are named the *ductless* glands; from their obvious connection with the process of sanguification, they are called *blood glands;* and, lastly, from their influence on the blood, being entirely exerted on that fluid within its vessels, they have been termed *vascular* glands. By some, the closed sacs already described (p. 604), as being found in the mucous membrane of the alimentary canal, if not classified as mere dependencies of the lymphatic system, are arranged with the ductless glands.

The organic processes proper to these ductless glands partake both of the characters of nutrition and secretion. Their substance is nourished like that of a muscle, but each, acting like a gland, separates from the blood something very special. On the other hand, although, like a muscle, and unlike a gland, they do not yield up their products directly by a duct, yet they doubtless impart to the blood, not merely the effete materials from their waste, but the substances formed by their special elaborative or assimilating power,—substances essential to the constitution of the blood itself. They might be termed *nutritive* or *assimilative* glands.

The Spleen.—This organ is a soft, dark, bluish body, attached to the cardiac end of the stomach; it is placed beneath the diaphragm, and is nearly or quite covered by the lower ribs. Its shape is a flattened oval, convex and smooth on its left surface, and concave on the right surface, which is applied to the great *cul-de-sac* of the stomach. Along this surface is a vertical fissure, named the hilus, sometimes notched in front, at which the bloodvessels, lymphatics, and nerves pass in or out. By these last-named parts, by a peritoneal duplicature, named the *gastro-splenic omentum*, and by a reflection of the peritoneum from the spleen on to the diaphragm, named the suspensory ligament, this organ is held in its place.

The size and weight of the spleen vary more than those of any other solid organ in the body, not only in different persons, but at different times in the same individual. This is chiefly owing to changes in the quantity of blood it contains. It usually measures about 5 inches in length, 3½ from front to back, and 1½ from side to side; its average weight is about 6 ounces, but it may vary from 4 to 10 ounces. Up to the age of forty, its proportionate weight to that of the body, is as 1 to 350; after that age, the ratio diminishes gradually to 1 to 700. In ague and other fevers, the spleen becomes enlarged by increase of substance, as well as by distension with blood, sometimes weighing 20 lbs. In certain diseased conditions of this organ, it has weighed 40 lbs.; on the other hand, it has been reduced to ¼ of an ounce in weight. Its specific gravity is about 1060.

Within the peritoneal *serous* covering, the spleen has a proper, strong, *fibro-elastic* coat, which is prolonged, at the hilus, into the interior of the organ, forming elastic sheaths around the bloodvessels, lymphatics, and nerves. Crossing in every direction between these sheaths and the inner surface of the elastic coat, are numerous slender elastic bands, named *trabeculæ* (*trabs*, a beam). In the spaces, or *loculi*, formed between these trabeculæ, outside the vessels, is contained the so-called *splenic pulp*. This is a soft, bluish-red or brownish mass, which may be pressed out from the intertrabecular spaces, and which becomes of a brighter red when exposed to the air.

The proper coat, the sheaths of the vessels, and the trabeculæ, consist of white fibrous and areolar tissues, mixed with elastic fibres, and contain, especially in animals, pale, fusiform, unstriped muscular fibre-cells. The splenic pulp consists of a colorless, granular parenchyma, mixed with numerous colored cells, with red blood-corpuscles of various size, shape, and state of aggregation. The colorless parenchyma is composed of round, oval, and fusiform nucleated cells, of nuclei, and of a granular matrix; it somewhat resembles the contents of the sacs of the solitary and agminated intestinal glands. The colored cells, or altered red blood-corpuscles of the splenic pulp, are peculiar to this organ. Some closely resemble the ordinary red blood-corpuscles; others, however, are smaller, and of a bright golden color, brown, or black; sometimes their contained pigment is gathered into a rod-shaped mass, or into some crystalline form, or is broken up into minute granules. Frequently they present the unique condition of agglomeration into little clusters or heaps, which are sometimes free, but sometimes inclosed in a delicate membrane, or encysted, so as to appear like large compound cells, containing from two or three, to as many as twenty altered blood-corpuscles.

Embedded in the splenic pulp, are numerous whitish vesicular bodies, measuring from $\frac{1}{6}$th to $\frac{1}{3}$d of a line in width, named the *Malpighian corpuscles* of the spleen; they are attached, in clusters, to the small arteries, and are supported on the trabeculæ, so as to appear like sessile buds or fruit upon a stem. Their envelope is partly derived from the fibrous coat of the artery, and partly from the outer harder layers of their contents. Their cavities have no communication with the bloodvessels on which they rest. Smaller bodies found in the spleen, are said to be Malpighian corpuscles in an immature state. They are composed of an extremely delicate, imperfectly fibrous, envelope, inclosing granular, nuclear, and nucleated-cell elements, like those of the splenic pulp itself.

The *splenic arteries*, entering at the hilus, ramify through the spleen by rapid subdivisions, without anastomoses, after the manner of the branches of a tree; many quickly divide into a coarse *capillary* network, which as speedily ends in the minute veins. The capillaries are most abundant in the splenic pulp, and also on the surface, and in the interior, of the Malpighian corpuscles. The smallest *veins* chiefly end, almost immediately, in larger ones, which form close plexuses and venous diverticula between the trabeculæ. Recent researches show, that whilst some of the arteries end in capillaries, from which veins arise in the usual manner, other of these vessels end in veins which suddenly enlarge, and, lastly, others even terminate in *lacunæ*, or spaces destitute of distinct walls, but bounded only by the elements of the pulp. (Gray, Billroth.) The interior of some of the veins presents a closely dotted appearance, from the numerous openings of little venules or diverticula around them. In the blood of the veins, splenic cells, altered blood-corpuscles, and clustered blood-corpuscles, are sometimes found, as from mutual extra- and intra-vasation. The blood of the splenic veins contains, however, fewer red corpuscles, but more fibrin, than other venous blood. On escaping from the hilus, the venous trunks unite to form the splenic vein, which, like the other tributaries of the portal system, is destitute of valves; some of the veins of the spleen pass on to the stomach, and join with its veins. The *lymphatics* of the spleen, divided, as usual, into a superficial and deep set, are by no means numerous. The mode of origin of the deep set is unknown. It has been supposed that the cavities of the Malpighian bodies communicate directly with the lymphatics, but this has not been proved. The spleen is supplied with comparatively few *nerves*, which are derived from the sympathetic system.

The splenic pulp, with its granules, nuclei, and nucleated cells, must be the seat of rapid nutritive and formative processes. The bulk of this organ increases in a marked manner during, and especially towards the end of, the process of digestion; an enlargement due, not only to an increase in the quantity of blood contained in the splenic vessels at that period, but also to a simultaneous increase in the quantity of all the microscopic elements of the pulp itself. Even the Malpighian corpuscles increase in size, and, it is said, in number, after the digestive process is completed. Their diminution in both respects, in states of exhaustion and innutrition preceding death, may account for their existence in Man having been denied. In starving animals, the Malpighian bodies are certainly few and small, or they may even disappear; whereas they become larger and more abundant in those which are well fed. The colored cells, or altered red blood-corpuscles, are likewise increased in mumber in highly nourished conditions of the body.

Since the colorless nuclei and nucleated cells of the spleen bear some resemblance to lymph-corpuscles in an early stage of development, and since, in certain conditions, such corpuscles, then considered as nascent white blood corpuscles, are found in large numbers in the blood of the minute veins and larger venous trunks, the spleen has been regarded, by Hewson and others, as one of the seats of formation of the white corpuscles of the blood, probably by the successive subdivision of old cells, thus acting, as it were, as a large *lymph-gland*, directly connected with the venous system. In certain cases of enlargement of the spleen white corpuscles are found in extraordinary number in the blood of the splenic vein, so as even to alter its color, and the number of these white corpuscles in the blood generally increases to such an extent that their proportion to the red corpuscles may be as high as 1 to 10. This condition has been named *leucæmia* or *leucocythæmia*, meaning white blood.

It has also been supposed (Kölliker, Funke, Billroth) that the spleen may be the seat of formation, in some yet undetermined way, of commencing red corpuscles. The small, bright yellow corpuscles inclosed in larger cells may undoubtedly be traced in the spleen, through a series of intermediate phases, into the ordinary flattened disc-like red corpuscle; but that these appearances indicate an upward development is doubtful. On the contrary, it is suggested that the red blood-corpuscles, having for a time performed their functions in the circulation, and having lived, as it were, their natural life, may really undergo disintegration and destruction in the spleen (Kölliker).

This hypothesis requires another mode of interpreting the microscopic appearances just described, as to the alteration, agglomeration, and encystment of the red blood-corpuscles in this organ. Since clusters of altered red corpuscles are found in the splenic veins it has been inferred that they proceed from the interior of the vessels and are extravasated into the pulp when sections are made of this organ; but if the undefined spaces or lacunæ, described by Gray and Billroth, exist, the presence of these altered blood-cells in both the pulp and the veins, and likewise the passage of the white nuclear and nucleated elements of the splenic pulp into the veins, would be easily explained. In support of the view that the red corpuscles decay in the spleen, it is said that when the spleen is removed in frogs these corpuscles become heaped or agglomerated in the blood itself. (Moleschott.) Moreover, as the quantity of fibrin in the blood of the splenic vein is greater than in any other part of the venous system, it has been suggested that this excess of fibrin is derived from the partial oxidation of the globulin of the red corpuscles, which are relatively diminished in number in the splenic vein. The oxygen necessary for this change is that belonging to the corpuscles. (Béclard.)

Active and important chemical changes, however, must occur in the capillaries and in the pulp of the spleen; but these are not yet understood. The chemical composition of the pulp, which resembles closely that of the blood, is very complex. In every 1000 parts there are 750 of water, 242 of organic, and 8 of saline and earthy matters. The organic substances consist chiefly of albumen, or some albuminoid body; besides this, there are traces of fat, and certain quantities of pigment like that of the blood, with smaller quantities of inosite, sarcin, leucin, tyrosin, xanthin, and even of uric acid. Soda and iron are the chief inorganic substances.

The variable size of the spleen under different conditions in the same person, has attracted much notice. It reaches its largest dimensions five hours after a meal, *i. e.*, near the termination of the process of chymification; seven hours later, provided no food has been taken, it is reduced to its smallest size, and is then also most deficient in blood. The elasticity of the whole fibrous framework of the spleen, including its proper coat, the sheaths of the vessels, and the trabeculæ, and also the large size of its veins and the absence of valves in them, facilitate the distension of this organ with blood during the turgid condition of the vascular system which results from the venous and lacteal absorption of the products of digestion. The resiliency of those elastic tissues will also favor the diminution of the organ in an opposite condition of the system. But the pale, muscular fibres of the spleen, which exist in abundance in the larger animals, and in smaller number in man, may, by alternate conditions of relaxation and contraction under the influence of the sympathetic system, or of some direct stimulus, materially assist in these remarkable changes of size. Electrical currents passed through the spleen cause that organ to contract. It has long been supposed that the alternate enlargement and diminution of the spleen serve a mechanical purpose, and that this organ acts as a diverticulum to the entire portal venous system, or to the vessels of the stomach and duodenum, in connection with certain changes in the circulation, dependent on digestion. The small size of the spleen during that process, is attributed to the bloodvessels of the stomach and duodenum, being at that period distended; whilst, when digestion is completed, those vessels diminish in size, and the spleen enlarges. The spleen is certainly quickly reduced in size, when the portal venous system is unloaded by hemorrhage or by purgatives, and it becomes enlarged in obstructive diseases of the liver and heart; but the idea of its serving specially as a diverticulum, is too mechanical, and but partially expresses its true function. A mere plexus of bloodvessels would have sufficed for such a purpose, without the co-operation of a peculiar parenchyma, like the splenic pulp; moreover, as already stated, not merely are the bloodvessels of the spleen distended during its periodic enlargement, but the splenic pulp itself, and even the little Malpighian bodies, are obviously increased in volume.

Notwithstanding much that is obscure in the history of this organ, it would seem, from the abundance and character of its microscopic elements, its chemical composition, its large supply of bloodvessels, and the peculiar relation of these to the pulp, that the spleen probably has for its office, as an assimilative or nutritive gland, the elaboration of the albuminoid constituents of the blood, and perhaps, as Hewson long ago suggested, the formation, like the lymphatic glands, of the germs of the white and red blood-corpuscles. The supposition that it is also the seat of a degeneration of the red corpuscles, is no contradiction to such a view. Some of the materials of the old corpuscles, as, *e. g.*, the pigment, may be used up again in the formation of new ones; for, like all ductless glands, the spleen, whilst, on the one hand, it abstracts materials from the blood, by special nutritive processes, on the other, it returns to that fluid, in some altered condition, all that it has so attracted from it.

The *suprarenal bodies* or *capsules.*—These organs, two in number, one on each side of the body, are small, flat, triangular, yellowish masses, placed on the summit of the corresponding kidneys, which they surmount like a cocked hat. Each measures about 1½ inch in width and 2 or 3 lines in thickness, and weighs nearly 2 drachms. They consist of an outer deep-yellow, firm, cortical portion, and of an inner dark, soft, medullary part, the whole organ being invested by a proper areolar coat, which sends prolongations into its interior. The *cortical* part presents numerous oval loculi, or spaces, in the areolar framework, placed end to end in little rows or columns, and arranged perpendicularly to the surface. These loculi were formerly thought to be oval or tubular closed vesicles, with distinct walls; but they are merely interspaces in the areolar framework of the organ. They contain a granular plasma, composed of an abundance of granules, with few or many fat particles, nuclei, and nucleated cells; towards the centre of the organ, the cells are larger and less regularly arranged, so that the columnar appearance is there lost. The *medullary*, or softer central portion, is composed of a delicate filamentous tissue, connected with the areolar tunic and framework of the cortical substance, and having in its interspaces also, besides bloodvessels, a granular plasma, containing nuclei and certain cells, the latter resembling the ganglionic cells of gray nervous substance (Leydig, Kölliker). The *arteries*, numerous and small, reach the suprarenal bodies at many points of their surface, and ramify between the rows of loculi, ending in capillary networks around them. The *veins*, also numerous, are collected into a plexus in the centre of the organ, where a venous sinus, sometimes taken for a gland cavity, is found. The *lymphatics* are said to be not very numerous. The *nerves*, however, are very large, and are derived chiefly from the sympathetic, but also in part from fibres of the pneumogastric and phrenic nerves.

From the quantity of blood received by the suprarenal bodies, and from the number and character of their microscopic elements, it is evident that the nutritive processes which take place within them are very active. Probably, like the spleen, they modify the blood passing through them, by subtracting from it, and returning to it, certain materials in an altered form; but their precise function is unknown, whether this be entirely elaborative, or partly destructive. A curious bronzed color of parts of the skin, has been frequently seen in disease of the suprarenal capsules (Addison, Hutchinson); but cases of similar cutaneous bronzing have been noted, in which the capsules were healthy (Parkes, Harley); moreover, these organs have been found diseased without bronzing of the skin (Kirkes, Day, Hutchinson). From the numerous cells, like ganglionic cells, in the medullary portion of these bodies, it has been suggested that this part may constitute a nervous apparatus, or be nutritively connected with the nervous system.

The Pituitary Body.—The posterior lobe of this body (p. 243) consists of true nervous substance; but its anterior lobe is composed of an areolar framework, forming loculi or spaces, which contain a granular plasma, nuclei, and nucleated cells of various forms, a structure somewhat, though not precisely, like that of the cortical part of the suprarenal capsules, or the vesicles of the thyroid body. It may, therefore, be temporarily classified with the ductless glands, though not from any established identity or similarity of function, which is wholly unknown.

The Thyroid Body.—This body, commonly named the thyroid gland, is a soft, reddish-brown, vascular organ, placed upon the front and sides of the upper part of the trachea, and reaching upwards to the sides of the larynx, to which it is suspended. It is formed of two lateral, somewhat pyriform *lobes*, joined together, at their lower and larger ends, by a transverse part, named the *isthmus*. The lobes are about 2 inches long, and measure $\frac{3}{4}$ of an inch in their thickest part. The thyroid body varies in weight from 1 to 2 ounces; it is larger in the female than in the male.

The thyroid body differs in structure from the other ductless glands, inasmuch as its proper tunic and framework of areolar tissue, forms loculi, in which are embedded multitudes of rounded closed vesicles, bounded by a distinct membrana propria, and lined by an epithelium. The vesicles, which measure from $\frac{1}{2000}$th to $\frac{1}{85}$th of an inch in diameter, contain a viscid, clear, albuminous fluid, in which are found nuclei and cells resembling the uniform epithelial-like layer. The arteries, four in number, and of considerable size, end, between and upon the walls of the vesicles, in a close capillary network, which empties itself into the *veins*. The *lymphatics* are numerous and large; their relations to the structural elements of the thyroid body are unknown; but it is supposed, from their relative size and abundance, that they are more concerned in returning the contents of the thyroid vesicles to the blood, than the lymphatics of the suprarenal bodies, or spleen, are, in regard to those organs.

Enlargement of the thyroid body constitutes the disease known as *goître*, in which the condition of white blood, leucocythæmia, or leucæmia, is often induced. In such cases, the nucleated cells of the thyroid body, and their contained nuclei, are smaller than usual, and, a fact of much interest, the white corpuscles of the blood are not only more numerous than in health, but are also unusually small. This so far favors the view, that the thyroid body may aid in the formation of the morphological constituents of the blood.

The thyroid body may also influence, like the other ductless glands, the chemical composition of the circulating fluid. The chief constituent of the glairy fluid of the thyroid vesicles, is of an albuminoid nature; but, unlike the splenic pulp, it contains a noticeable quantity of fatty matter. Its extractives and salts differ in no important particular from those of the blood.

Some physiologists have supposed that the thyroid body acts mechanically, as an occasional diverticulum for the blood concerned in the cerebral circulation; but the evidence of this is even less than that adduced on behalf of a similar hypothesis concerning the spleen and the portal circulation.

The *goitrous enlargement* of the thyroid body, which produces such unsightly disfigurement of the neck, is most frequently met with in females. It prevails in particular countries, and in particular districts of those countries. Thus, it is met with chiefly in the north of Italy, and in certain cantons of Switzerland, most markedly in the canton of the Valais. In other European countries, it is met with much less frequently; but still asserts a preference for particular districts. In England, it is most common in Derbyshire, and hence its popular name, the Derbyshire neck; but it is observed in many other scattered localities. In spite of careful investigations, involving researches into the climate, solar influence, atmospheric peculiarities, rain-fall, soil, and drinking-water of those districts, and into the manifold conditions of existence of the people, the true cause of goître has not yet been inductively ascertained. It is more common in the country than in towns, and is almost entirely confined to hilly and mountainous districts, being more particularly observed in the valleys of those districts; but it is not prevalent in all elevated or mountainous regions. It has been variously attributed to the deficiency of oxygen in the higher levels of the atmosphere; to the want of solar light in valleys, especially since, as is alleged, it prevails more on the southern, and comparatively sunless, sides of such valleys; to the habitual use of drinking-water derived from the melting of glaciers or of snow, and therefore almost entirely destitute of saline and earthy salts; and, again, on the contrary, to the presence of lime, but particularly of magnesia, in such water, derived from the limestone or magnesian limestone, often found in districts in which goître is common. Lastly, its special prevalence amongst females, has been assigned to the custom, in hilly districts, of carrying water, or other heavy substances, on the head, by which it is alleged that the muscles of the neck compress the veins, and so cause congestion, and ultimate enlargement of the thyroid body.

In the canton of the Valais, where go tre prevails in its most intense form, it is often associated with an arrest of development of the whole frame, especially of the skull and brain, which constitutes the condition known as *Cretinism.* The Cretin may, indeed, be said to be a small idiotic human being, distinguished from ordinary idiots, by the thyroid body being enlarged or goitrous. But in the Cretin districts, persons of full stature, of duly proportioned cranial and cerebral development, and of ordinary intellectual capacity, are seen with goitres larger even than those found in Cretins themselves.

The *thymus body*, or *thymus gland.*—This ductless gland is a temporary organ in the animal economy. Present in the embryo, it attains its largest relative size to the body in the infant, and seems to be most active in function a short time after birth, growing up to that period even faster than the body. It then continues to grow, so as to keep pace with the rest of the body, up to the age of two years; but soon, it no longer increases with the body, and, at about twelve years of age, is usually changed into a fatty mass; according to Friedleben, it may grow a little after the second year, and not become fatty until after puberty. Finally, especially in thin persons, it gradually wastes, so as to leave nothing but a mere vestige behind.

In its most complete condition, it forms a double organ, composed of two lateral irregular *lobes*, joined by a central mass, and situated partly in the lower region of the neck, and partly in the thorax, lying upon the trachea and the great bloodvessels. It measures, at birth, about 2 inches in length, and weighs half an ounce. It is a soft pinkish-gray body, consisting on each side of a string of compressed lobules, connected together by an elongated part, like a cord. A strong areolar coat incloses and connects the various lobules, and sends intervening coverings between their ultimate subdivisions. The lobules, or acini, are composed of a soft milk-white parenchyma, consisting of granular matter, nuclei, and nucleated cells; the central part of each lobule is so soft or fluid that, when opened, a cavity is found, which extends into the secondary lobules, of which the primary ones are composed. The cord which connects the lobules together contains the same parenchymatous substance, and is likewise soft or fluid in the centre, so as to form a cavity, called the *reservoir of the thymus;* this communicates with the soft cavities of all the lobules, and also with certain small sacculi situated in its walls. Each lateral half of the thymus has its proper reservoir, the two sometimes communicating through the central transverse mass. The cavities within the lobules and connecting cord are not lined by a distinct limitary membrane and epithelium; the fluid within them is milky white, and resembles chyle. It contains nuclei and nucleated cells, similar to those of the white parenchyma itself. Many of these closely resemble the developing lymph-corpuscles found in the loculi of the lymphatic glands, and, therefore, also the white corpuscles of the blood. No minute fatty molecules, similar to those forming the "molecular basis" of the chyle, are found, however, in the white fluid of the thymus. To chemical analysis, this body yields about 20 per cent. of solid matter, chiefly albumen, some gelatin, only a little fatty matter, and traces of sugar, leucin, sarcin, xanthin, salts of formic, acetic, succinic, and lactic acids, chloride of potassium, and alkaline and earthy phosphates. The bloodvessels of the thymus are large and numerous; the *arteries* penetrate to the central cavity, and thence ramify towards the surface of the lobules; the *capillaries* traverse the soft white parenchyma in all directions, the chief terminal plexuses being near the surface of the lobules; the *veins* are large and, what is unusual, do not accompany the arteries. The *lymphatics* are also numerous and of great size, terminating, some in the thoracic duct, others in the right lymphatic duct, and others directly in the neighboring large veins. It is supposed that the lymphatics assist in conveying the contents of the cavities of the thymus into the blood; but their direct communication with those cavities has not been demonstrated. The *nerves* are small, and are derived from the pneumogastric nerve, and the sympathetic system.

The office of the thymus would seem to be, to prepare an *albuminoid* pabulum, fitted for the formation and maintenance of the blood, exactly at that period of life when growth is relatively most rapid, *i. e.*, in the earliest years of infancy. It is possible, moreover, that its nuclei and nucleated cells, especially those which resemble the lymph-corpuscles, are the germs of future white blood-corpuscles, a view especially urged by Hewson. The almost complete absence of fatty matter, hydrocarbons, or carbhydrates, from the thymus, as well as from the thyroid body and spleen, would seem opposed to the idea, that any of these organs stored up such substances for the direct purposes of combustion. Yet it has been conjectured that the fluid of the thymus, forms a reserve of material suited for oxidation in the respiratory process, at a time when such matters, derivable from the waste of muscular tissue, are by no means abundant. (Simon.) Later, however, in fully nourished children, the thymus becomes quite fatty, its nucleated cells being converted into adipose cells, which might then yield their fatty combustible matter to the blood. In the hibernating Mammalia also, this organ continues to grow more rapidly than the body, up to the adult period of life, and, when thus persistent, contains much adipose matter. This is also said to be the case in most Reptiles. It was at one time held, that the thymus body acted as a diverticulum, in regard to the pulmonary circulation, in the child.

The *closed sacs* of the *tongue*, *tonsils*, *pharynx*, *stomach*, and *intestinal canal.*—These, as elsewhere described (p. 604), whether solitary or clustered, may be regarded as minute representatives of the larger ductless glands, to which in their closed form, their vascularity, and their albuminoid, granular, nuclear, and nucleated cell-contents, they bear a certain generic resemblance. They might, indeed, be compared to the Malpighian bodies of the spleen; but they differ from the vesicles of the thyroid body, in having no distinct cavity lined by an epithelium. They might be said to stand in the same relation to the larger ductless glands, that the small and simple tubular glands of the stomach and intestine do to the large secreting glands, with extensive excretory ducts.

The *ductless* or *vascular glands* considered generally.—When the structure of these organs was less understood than it is at present, they were sometimes supposed to possess parts analogous to the terminal acini, vesicles, or dilated ends of the ducts of true secreting glands; and the absence of the ducts themselves was said to form the most marked distinction between them and these glands. But the thyroid body alone has distinct vesicles, limited by a membrana propria and an epithelium, and so far approximating to the characters exhibited by the commencing ducts of a secreting gland. In the spleen, and even in the suprarenal bodies, the inter-trabecular areolæ, and the columnar loculi, are not so surrounded, but are mere interspaces in an areolar framework. The minute encapsuled Malpighian bodies of the spleen, and likewise the closed sacs of the alimentary canal, have no lining epithelium or true basement-membrane. The branching sacculated canals, and secondary cavities, or acini of the thymus, cannot be compared to true glandular structures, for they also are destitute of a lining membrane and epithelium. Indeed these ductless glands, instead of resembling the secreting glands with ducts, possess characters approximating them rather to the lymphatic glands, with their numerous loculi and albuminoid corpuscular contents; but they differ in this, that their cavities do not open directly into the lymphatic vessels.

Considered generally, their proper parenchyma, with its granular plasma, nuclei, and nucleated cells in various stages of growth, constitutes their most important and characteristic anatomical element. The rest of their structure is either the framework of the organ, or consists of the bloodvessels, lymphatics, and nerves.

The physiological influence of these organs in the economy must be exercised on the blood, and must be exerted, especially through a nutritive process, by the nuclear and nucleated cell-like constituents. The blood entering such an organ yields to it, by exudation through the walls of the capillaries, a common plasma, from which, by a nutritive process dependent on the special attractive, selective, and assimilative powers of the microscopic elements, certain special materials are separated. The residue of the plasma re-enters the circulation, either directly through venous, or indirectly through lymphatic absorption, as in every instance of simple nutrition. Hence, in the first place, the blood which passes through these organs must be modified, as in all nutrition, by the abstraction of certain of its constituents; and the effect is peculiar in each organ.

But, secondly, the proper substance of these ductless glands cannot remain unchanged and inactive, subject to no further metamorphoses, and productive of no special influence upon, or service in, the economy. On the contrary, it would seem certain, that something must also be added, by their agency, to the blood as it passes through them. The materials attracted from the blood by their proper substance, and elaborated within them by a sort of nutrient secretive act, are returned, more or less altered, into the blood current. This may chiefly be accomplished by solution and venous absorption in the spleen, suprarenal bodies, and thyroid body, or by lymphatic absorption in the thymus and closed sacs of the alimentary mucous membrane, or by occasional opening of the loculi into the veins, as in the spleen, or into the lymphatics, as conjectured by some to be the case in the thymus.

By both subtraction and addition of material, the blood must be specially modified, as it passes through those organs, which, from their various actions, contribute, therefore, to the elaboration and maintenance of the complex chemical constitution of the blood. It is for the preparation of the *albuminoid* constituents of the blood, that these organs are destined, and not for the formation of fatty matter, which is so scanty in their composition. Their action upon the coloring matters, which are also albuminoid, may be, in the case of the spleen and suprarenal bodies, to decompose or re-compose those peculiar substances. Moreover, from the resemblance of the microscopical elements of their abundant and characteristic parenchyma, to the white blood-corpuscles, they are probably concerned in the formation of those bodies, and therefore of the future red corpuscles, assimilating the nutrient plasma of the blood into distinct morphological elements, just as the lymphatic glands and vessels develop a corpusculated fluid in their interior. Hence, both chemically and morphologically, the blood glands are believed to contribute to the important process of sanguification. The products of nutrient secretion formed by these organs all enter the systemic veins, excepting those elaborated by the spleen, which first enter the portal blood, and so pass through the liver, before they reach the right side of the heart, to be sent to the lungs.

It is remarkable that all the large ductless glands are present and active during embryonic life, and also in the most active period of growth after birth. The suprarenal bodies at first, in the embryo, much larger than the kidneys, are, in the adult, only $\frac{1}{28}$th part of the weight of those glands. The thymus especially ceases, after birth, to grow in proportion to the rest of the body, and then gradually wastes; a positive relation has been observed in young animals, between its size and the state of their nutrition. The thyroid body and the pituitary body are also larger proportionally in the embryo and the infant, than in the adult; but they continue to be present throughout life. At birth, the weight of the thyroid body, as compared with that of the body generally, is as 1 to 250 or 1 to 400; but it soon ceases to enlarge with the body, for, after three weeks, the proportions are as 1 to 1166, and in the adult only as 1 to 1800 (Krause). The spleen, however, enlarges with the body, and maintains its proportionate size; but it is undoubtedly largest in the most active period of life, about early manhood. As to the closed sacs of the tonsils, tongue, pharynx, and solitary and agminated glands of the stomach and intestine, they exhibit a continuous development with the rest of the body, and are permanent structures.

Finally, it would seem that, whatever may be the general or special uses of the ductless glands, some of them, at least, are not absolutely essential to life. The thymus, though very large in the early period of development and growth, ultimately disappears as a distinct organ. The thyroid body may be totally altered by disease, becoming cystic, indurated, or filled with earthy deposits, without serious detriment to the health. The spleen has been extirpated from animals, without any obvious ill consequences, and, it is said, in a few cases, even from the human body. In certain animals, the spleen is multiple, minute detached spleens, named splenculi, existing near the principal organ. When the latter is removed, the splenculi become enlarged, and so supply, physiologically, the place of the extirpated spleen. In other cases, the lymphatic glands of the neck and axilla have become increased in size; and, on the whole, the result of such experiments would seem to show, not the want of importance of the spleen, but that its functions may be performed, as it were, vicariously, by other organs of the body. The same may be true in cases in which the thyroid body is diseased. It is said, however, that in animals, after the removal of the spleen, the quantity of iron in the blood is diminished, and that the appetite becomes voracious, and the temper fierce. Removal of the suprarenal bodies is fatal; according to some, directly, owing to the retention of some poisonous substance in the blood; according to others, indirectly, as a consequence of the incidental injury to the nerves and other neighboring parts. (Harley.)

THE LIVER CONSIDERED AS A BLOOD GLAND. GLYCOGENIC FUNCTION OF THE LIVER.

The action of the ductless or nutritive glands, viz., that of extracting material from the blood, elaborating it, and, instead of eliminating it by ducts, returning it into the blood, by means of venous or lymphatic absorption, is, to a certain extent, imitated by the liver, the largest secreting gland in the body. In the embryo, the liver is, indeed, a true *blood gland*, blood-corpuscles even being developed in its capillary network. But probably then, and certainly after birth, the hepatic nucleated cells, which secrete the bile, like the special parenchyma of the ductless glands, attract and assimilate material from the blood, and form a peculiar substance, which is not discharged by the bile-ducts, but enters the blood either through the veins or the lymphatics; most probably, however, through the former. But this substance is not albuminoid, like the supposed products of the assimilative action of the ductless glands; it is amyloid, forming an *animal starch*, closely resembling the amylaceous substances developed so abundantly in the Vegetable Kingdom. By Claude Bernard, its discoverer, it was named *glycogène*, from its yielding sugar when mixed with ferments; it has also been called *hepatine* (Pavy), and *zo-amyline* (Rouget). It is obtained by bruising the substance of the liver in water, boiling the fluid to coagulate the albumen, filtering through animal charcoal, and then precipitating the substance sought for, by means of pure acetic acid or alcohol. It is white, tasteless, flocculent, and readily soluble in pure water; with iodine, it forms a reddish violet compound, the color of which disappears at a temperature of 176°, but returns on cooling. It does not reduce the salts of copper. Minute granules, apparently covered with an albuminous fibrin, are found in the hepatic cells; these are not fatty, being insoluble in ether, but they behave with reagents in such a manner as probably to be particles of this substance. Its atomic composition is identical with that of starch, dextrin, and grape sugar, $C_6H_{10}O_5$, but its general properties are intermediate between those of starch and dextrin. Like dextrin, when dissolved in water, glycogen is immediately transformed into grape sugar, by albuminoid ferments, as is proved by the solution then decomposing the salts of copper, and turning the rays of polarized light to the right hand, and also by its readily passing into the alcoholic or the lactic acid fermentation.

An amyloid or cellulose substance was long ago found in the Tunicated animals (Schmidt), and amyloid bodies have since been observed in other Non-vertebrate animals. (Carter.) In a peculiar degeneration of various tissues and organs of the human body, as of the nervous substance, muscles, liver, spleen, kidneys, prostate, and other parts, amyloid bodies, or so-called *corpora amylacea*, have been frequently met with. (Virchow, Meckel, Rouget.) Bernard himself detected a glycogenic substance in the placenta, and in various embryonic tissues, especially in the muscles, though he thought it disappeared from them in after-life. Amyloid substance is sometimes certainly present in healthy muscle; it has been found in the muscles of the horse a few hours after feeding, though, in the fasting condition, none is present. The occurrence of a starchy substance, is, therefore, as Rouget believes, by no means confined to the tissues of vegetables, nor even to the liver amongst the animal organs, but this substance may, under certain conditions, be a product of the nutritive action of nearly all the tissues.

The glycogenic function of the liver is, however, most remarkable, and constitutes a special assimilative office, superadded to its ordinary use of secreting bile. Since neither glycogen nor sugar is found in the bile, it is obvious that, if this animal starch be employed in the economy, it, or some product of it, must enter the blood, either directly through the veins, or indirectly through the lymphatics. It is now known that, not the glycogen itself, but the sugar resulting from its transformation, is absorbed by the hepatic veins. The detection of considerable quantities of sugar in the blood of the hepatic veins and of the right auricle of the heart, led, indeed, to the discovery of the glycogenic function of the liver. At first it was supposed by Bernard, that the sugar itself was formed by that organ. That this is not derived directly from starch or sugar in the food, is shown by its occurrence in animals killed after being fed, for at least a month, on meat alone. That the sugar comes from the liver, is shown by the fact, that after injecting water into the portal vein until the fluid escaping from the hepatic veins is colorless and free from sugar, it is possible, after waiting a certain number of hours, to obtain by injecting more water, a further supply of sugar. Hence Bernard concludes, not merely that the sugar is produced in the liver, but that it must be formed by a slow chemical, and not necessarily vital, change of an amyloid substance within the liver. By treating the liver-substance in the mode already mentioned, the glycogen is then obtained separately.

The transformation of starch into sugar, by salivin, suggested the idea that this glycogen of the liver also requires a special ferment to induce its metamorphosis. It was thought that, if not the salivin or pancreatin, this ferment might be some albuminoid product of one of the ductless glands; but extirpation of the salivary glands or pancreas, of the spleen, suprarenal bodies, thyroid, or thymus, in a series of experiments on animals, threw no light on the question. (Schiff.) The albuminoid substance is probably formed in the liver itself; for, whereas glycogen, like starch or dextrin, is not easily transmissible through the coats of the hepatic vessels, it is probably converted into the readily dialyzable sugar, before it is taken up by those veins. The fibrin and albumen of the blood, whether arterial or portal, will also convert dissolved glycogen into sugar. A boiling temperature destroys the power of the ferment, whatever this may be.

It has been suggested by Pavy that, although an amyloid substance abounds in the liver during life, no sugar, or but very small traces of it, are then present in this organ; and that, except in disease, transformation of the hepatin into sugar is, for the most part, a post-mortem result. This observer found no great difference in the quantity of sugar in the various large bloodvessels, either in the arteries, or in the hepatic or portal veins; the quantity detected was very small, averaging about $\frac{1}{16}$th of a grain in 100 grains of blood. In the liver-substance itself, macerated, instantly after death, in caustic potash or in very cold water, no sugar could be detected, though the hepatin or glycogen was then extracted. Most physiologists, however, coincide with Bernard, in believing that the formation of sugar in the liver is constantly taking place during life; and that the accompanying decomposition of the glycogen into sugar may explain the relative higher temperature of the blood which has been observed in the hepatic veins.

The average quantity of sugar obtainable from the liver of the horse and calf, varies from 4 to 2 per cent.; in the rabbit's liver, it is about 2.5 per cent., and in Man, as noticed in healthy, recently executed criminals, about 2 per cent. (Bernard.) By others, sugar has been found in the liver of Birds, Reptiles, and Fishes, though in the cold-blooded animals the quantity is small; it has even been detected in the liver of the Mollusca. (Bernard.) It is more easily obtained from the veins than from the substance of the organ. The relative proportion found in the portal blood, in the systemic venous blood, and in the arterial blood of animals fasting, or fed only on flesh, is about .06 parts in 100; whereas, in the hepatic blood, the quantity is usually about 1 per cent. In fully fed animals, especially after a meal containing starch, the quantity in each kind of blood is increased. In one experiment on a well-fed horse, killed soon after digestion, the proportion of sugar found in the liver was nearly 2.3 per cent.; whilst that in the hepatic vein was about 1.1, in the lymph .44, in the chyle .22, and in the blood generally .065. (Poiseuille and Lefort.)

The glycogen of the liver being admitted to be the source of the sugar found in the hepatic blood, the origin of the glycogen itself is yet undecided. Some have questioned the power of animal tissues to form an amyloid substance, and have suggested that the glycogen of the liver is derived from the starchy matter of the food, which might be supposed, in Herbivorous animals, to be partly accumulated, in a modified form, in the hepatic cells or elsewhere. More sugar, certainly, is obtainable from the livers of Herbivorous than from those of Carnivorous animals, and more from Herbivorous animals recently fed on amylaceous food; but glycogen continues to be formed in the livers of fasting or actually starved animals, and of animals fed for a month or more exclusively on flesh. In such instances, the glycogenic substance found in the liver cannot be derived directly from food, but is formed by some action of the hepatic cells, in which, as already mentioned, minute grains, apparently of an amyloid nature, have been detected. The constituents of the flesh used as food, which can be thus metamorphosed by the hepatic cells, are fat and albuminoid substances; for the small quantities of amyloid matter sometimes found in flesh, and of inosite or muscle-sugar always present in it, which is incapable of the alcoholic fermentation, and does not turn the rays of polarized light, are not sufficient to produce it. By some, it has been supposed that the hepatic cells have the power of decomposing the neutral fats of the food into glycerin and the fatty acids, stearic and oleic; furthermore, that the former is the source of the glycogen, and that the latter assist in the formation of the fatty acids of the bile: thus, 2 of glycerin, *i. e.*, 2 $(C_3H_8O_3)$ + 2 of oxygen (O_2), are equal to 1 of glycogen $(C_6H_{10}O_5)$ + 3 of water 3 (H_2O). It has been objected to this, that the formation of sugar and of bile in the snail, has been observed to be an alternately performed function. (Bernard.) Another mode of origin of the glycogen from fatty matter supposes that the conjugated fatty acids of the bile, taurocholic and glycocholic acids, are first formed, that they are then reabsorbed from the intestinal canal by the portal vein, and are decomposed into glycogen and a nitrogenous product, which is ultimately converted into urea, and eliminated by the kidneys; for dogs with biliary fistulæ appear to have no glycogen in the liver, and other dogs, after long fasting, if fed with taurin, show an abundance of glycogen in that organ. By some, again, albuminoid principles are supposed to be decomposed in the hepatic cells; according to one view, the products are glycogen and the two conjugated biliary acids, one of which contains nitrogen, and the other, in addition, sulphur; according to another view, they are glycogen, and various nitrogenous bodies, such as creatin, creatinin, and other substances, which are ultimately excreted as urea. The continuous formation of sugar in the eggs of birds, during incubation, shows that glycogen may be formed independently of amylaceous food, and its origin from albuminoid matter is rendered probable, from the fact that in animals fed on fat or oleaginous food alone, or even on pure starch, as distinguished from vegetable food containing starch mixed with other constituents, the glycogen is much diminished in quantity (Stokvis); whereas, in those fed on gelatin it is almost normal in quantity, and attains its maximum in animals fed on highly albuminous diet. (Bernard and Schmidt.) The experiments of Dr. Pavy alone give opposite results, showing the greatest amount of sugar in animals fed on vegetable food only; but the increase of sugar then observed by him might be partly owing to sugar formed from the food itself. He found, in the livers of dogs, the proportion to be about 7 per cent. with a pure animal diet, 14.5 per cent. with meat and sugar, and 17 per cent. with a purely vegetable diet. It is believed that the glycogen found so abundantly in the muscles of the embryo, the inosite formed in the muscles after birth, and the small quantity of glycogen which they contain after the liver has commenced its glycogenic office, are also derived from the decomposition of albuminoid substance into glycogen, and some oxidizable nitrogenous body, such as creatin or creatinin.

The *use* of the glycogenic function of the liver is supposed to be that of continuously supplying an easily oxidizable material for the purposes of maintaining animal heat and motion. Sugar is a very unstable element in the presence of oxygen with albuminoid substances, such as are found in the blood. As already stated, the quantity of sugar found in arterial blood, that is, in the blood which has passed through the lungs, is much smaller than that in the hepatic venous blood. Besides undergoing oxidation, like the sugar of the food, so as to form carbonic acid and water, the liver-sugar may also be capable of transformation, through the assimilative force of some of the animal tissues or organs, into fatty matter, or some other substances necessary to the living economy.

The sugar may likewise act as a solvent of the carbonate and phosphate of lime in the blood. It has also been said to aid in the decomposition of albuminoid into oleaginous or other compounds.

When animals are covered with varnish, which arrests the cutaneous transpiration, and interferes with the respiratory changes and the development of animal heat, both the sugar of the hepatic blood, and the glycogen of the liver, soon disappear; but, by then employing artificial warmth, they may be again formed. In hibernating animals, in which the respiratory process is also reduced to a minimum, the formation of sugar continues, but its oxidation, after it passes into the circulation, is imperfectly carried on, or entirely ceases, so that it accumulates in the blood, and even appears in the urine. So, too, in the disease known as diabetes mellitus, the sugar found in that excretion is supposed to depend upon the accumulation of sugar, probably of liver-sugar in the blood; for, in such cases, other secretions and excretions also exhibit traces of that substance. That the sugar excreted by the kidneys in diabetes is not formed in those organs, is certain; and it has been noticed that if the blood contain $\frac{1}{3}$d of a grain of sugar in 100 grains, this substance is no longer completely consumed, or oxidized in the combustive processes of the economy, but appears in the various secretions and excretions, most abundantly in that from the kidneys. In the diabetic condition, not only may the sugar formed in normal quantity accumulate, from not undergoing decomposition, but the liver may generate more sugar than usual.

A temporary and remediable diabetes may occur from the undue ingestion of sugar, or sugar-forming substances, with the food. Moreover, many medicinal agents appear to determine an increased activity of the glycogenic function of the liver, producing an artificial diabetes; such are morphia, strychnia, and phosphoric acid, in large quantities. (Pavy.) Asparagus has a similar effect; so likewise has the injection of various stimulating fluids into the portal vein (Harley), and the inhalation of acetone and benzine. Caustic potash and carbonate of soda check the formation of sugar. (Pavy.)

[Dr. W. A. Hammond, in his experimental investigations on the ingestion of starch as an article of food, found, at the end of the fifth day of his consumption of starch as his sole article of food, that sugar appeared in his urine and continued during the remaining ten days of experimentation. (Hammond: *Physiological Memoirs.* Philada.: J. B. Lippincott & Co., 1863.) F. G. S.]

An experiment, first made by Bernard, in which an artificial diabetes is produced, shows that certain parts of the nervous system influence the sugar-forming function (pp. 282, 312). It illustrates the power of the nervous system over the nutritive and assimilative processses, and may explain certain cases of ordinary diabetes. By passing a needle through the back of the occipital bone in the rabbit, and irritating with its point, the floor of the fourth ventricle, from near which the deep roots of the pneumogastric nerves spring, he produced an artificial diabetes mellitus. Moreover, irritation of the cerebrospinal axis, from the cerebral peduncles down to the roots of the pneumogastric nerves, on the sides of the medulla oblongata, increases the formation of sugar in the blood, and gives rise to temporary diabetes. On the contrary, division of the pneumogastric nerves in the neck, that is, above the point where their branches to the lungs are given off, appears to restrain the formation of sugar in the system; section of the spinal cord below the origin of the phrenic nerves, has apparently a similar effect.

It has been suggested that these effects are not direct upon the liver itself but that, in the normal condition, a certain stimulus, perhaps associated with the demand created by the process of oxidation going on in the lungs, proceeds from those organs, through the pneumogastric nerves to the medulla oblongata, and is thence reflected through other nerves, to the liver, where it excites or regulates the glycogenic action. On interrupting the continuity of this nervous chain, by division of the pneumogastric nerves, the formation of sugar is checked. Disturbances in the respiratory function, induced through the nervous system or otherwise, may favor the formation of sugar and its accumulation in the blood, and so produce diabetes. It is said, furthermore, that division of the great splanchnic nerves, or of the sympathetic nerves in the neck, increases the formation of sugar in the liver; this may depend, not on an increased formation of glycogen, but on the increased quantity of blood then admitted to the liver, owing to dilatation; through the action of the vasi-motor nerves, of the small arteries of the abdominal viscera generally. The larger flow of blood through the portal system and liver may change the glycogen already formed, into sugar, more quickly than usual, and thus favor its more rapid escape from the hepatic cells. This explanation may also apply to the effect of irritation of the back of the medulla oblongata, in the floor of the fourth ventricle, for the vasi-motor sympathetic nerve fibres of the viscera of the abdomen have been proved to pass down in that part of the medulla from the cerebral peduncles and optic thalami. (Schiff.)

The formation of glycogen by the liver, its conversion into sugar, and the entrance of this into the blood by the veins, establish the importance of this gland in the process of Sanguification. These facts also suggest the possible occurrence of some similar but yet unknown actions in other secreting glands, and also in such tissues as muscle and nerve, as well as in the ductless glands.

Sanguification and the Blood Glands in Animals.

In the Vertebrata generally, the processes concerned in the formation of the white and red corpuscles, and the fluid matrix of the blood, are similar to those which occur in Man. Besides an absorbent system, the blood-glands or ductless glands, are found in all the Vertebrate Classes, but they do not all exist in every Class. The spleen is almost universally present; the suprarenal capsules disappear earlier in the descending scale, the thyroid body and the thymus still sooner.

The *spleen* is present in all cases, excepting in the myxine fishes. It always possesses its peculiar structure and characteristic dark red color; it varies much in shape, even in Mammalia, being, in different cases, round, oval, much elongated, lobulated, or even multiple. The latter condition is seen in the dolphin. The existence of supernumerary spleens, or *splenculi*, in dogs, cats, and other animals, has been already mentioned. In Birds, the spleen is small, and either round, oval, fusiform, or flat; in Reptiles, Amphibia, and Fishes, it is of variable size, and differs in form according to the general shape of the body. In Birds and Reptiles, this organ is usually attached to the pancreas; in Reptiles and Fishes, it is rather connected with the intestine than with the stomach, as in Mammalia. The existence of the Malpighian bodies is doubtful in the Amphibia, and denied in Fishes; but the large aggregated blood-cells exist in all Vertebrata.

The *suprarenal* bodies are present in all Mammalia, Birds, Reptiles, in most, if not all, Amphibia, and in all but the lowest Fishes. They are always of a yellowish, ochreous, or golden hue. In Mammalia, they are of various forms, commonly three-sided, but often elongated, cylindrical, oval, round, or even crescentic. They are sometimes a little removed in position from the kidneys, as in the elephant and seal. They are large in Rodentia, and small in Carnivora, especially in the seal; their size as compared with the kidney, is, in the guinea-pig, as 1 to 4; but in the seal, only as 1 to 150. In the Cetacea, they are lobulated, and supernumerary suprarenal bodies are met with in many animals. In Birds, these organs are small, and often lobulated. In Reptiles they are usually placed on the renal veins, or vena cava inferior; in the Ophidia, the right one is the larger. In Batrachia, they are very small, broken up, or often indistinct, and embedded in different parts of the kidney. In Fishes, too, when present, they are usually small and multiple, and often found even at the back of the kidney; in the sturgeon and Cyclostomatous fishes, their existence is doubtful.

The *thyroid* body is attached to the larynx in the Mammalia only. In Birds and Reptiles, it is placed low down in the neck, or even in the chest, near the inferior larynx. Its position seems to be regulated rather by its vascular connections, than by any peculiar relation to the proper larynx. In Reptiles also, it is in the thoracic cavity, close above the heart. As to Fishes, it has been supposed that the vascular organs known as *pseudo-branchiæ* attached to the branchial apparatus, are the homologues of the thyroid body; but the balance of evidence is opposed to this view, and if the thyroid body exist at all, it is only occasionally, as a small isolated mass, lying on the bulbus arteriosus.

The *thymus gland* is well marked in the Mammalia, being either confined to the thorax, as in the Carnivora, Insectivora, and Marsupialia, or having also shorter or longer cervical cornua, or extensions upwards into the neck, as in Quadrumana, Bats, Rodents, Solipeds, and especially in the Ruminants. In the ox tribe, its cervical part extends up to the lower jaw, forming the *neck sweetbread*, and, from the calf, is the part sold as the best sweetbread. This organ is a conjoined bilateral mass; its structure is lobulated and sacculated, as in Man. It is largest in the young animal and disappears later in life. It is said to become larger in hibernating animals. In Birds it is represented, but only in the chick and young bird, by a small tube, having slight dilatations upon it; but it is sometimes divided off into sacs. In young Reptiles, it has also been found, and likewise in the tadpoles of most Amphibia; but not, it is said, in the siren or proteus, in which the lungs are the least developed. In Fishes, the thymus is absent.

In the Amphioxus, none of those ductless glands are found, not even the spleen; in this animal, no colored blood-corpuscles exist.

In the Non-vertebrata, these glands and colored blood-corpuscles are equally absent; nor is any organ recognized in them, as being specially concerned in the process of sanguification. The liver, however, is almost universally present, and its glycogenic function has been detected in the snail; and as it is a blood gland, forming blood corpuscles in the Vertebrate embryo, it may suffice for the wants of the Non-vertebrate organism in reference to the formation of blood. Such organs as the spongy masses around the great veins in the Cephalopods, may, perhaps, be concerned in sanguification.

SECRETION.

SECRETION IN GENERAL.

Secretion (*secernere*, to separate) is the separation, by a gland or membrane, of certain materials, in a more or less fluid state, from the blood, and their escape, by means of proper ducts or openings, or from a smooth membrane, on to the surface, or into the interior, of the body. This general process is, however, divisible into *secretion proper* and *excretion*. In *secretion proper*, the *products* are *formed* by a *nutritive process*, the result of a special attractive, selective, or assimilative power, possessed by some epithelial structure; and moreover, after being discharged from the mouths or ducts of the glands, or from the surface of membranes, they are used for certain purposes in the living economy. In *excretion*, the *educts* are rather *eliminated* from the blood through the agency of special structures, also epithelial; and they are henceforth cast out from the body as effete, useless, or even injurious substances.

Secretion may be performed by glands, or by membranes; but excretion is always effected through the agency of glands.

The secreting glands are the liver, pancreas, the salivary and lachrymal glands, the true mucous glands of the nose, mouth, fauces, pharynx, œsophagus, the duodenum, the simple tubular glands of the stomach and intestines, other minute glands associated with the ducts of some of the larger glands, the sebaceous and Meibomian glands, and lastly the mammary glands. The secreting membranes are the mucous, serous, and synovial membranes. The excreting or excretory glands are the kidneys, and the sweat glands of the skin; to a certain extent, the liver, and perhaps the intestinal tubuli, especially those of the great intestine; perhaps, also, the sebaceous cutaneous glands;

and, lastly, the lungs, which may be viewed as excreting glandular organs, destined to eliminate carbonic acid from the blood.

In certain forms of *secretion*, the separated products closely resemble those contained in the blood itself, such as the albumen of the serous and synovial fluids. Thus, the serous and synovial secretions consist of little more than the transuded materials of the plasma of the blood, unaltered in chemical character, but modified in their relative proportions. The casein of milk is also merely a modified form of albumen. In other more special secreting processes, there are formed, not as mere transudations, but as the result of peculiar assimilative actions, substances not present in the blood itself, but, nevertheless, little removed in chemical character from its albuminoid constituents; such, *e. g.*, as the pepsin, pancreatin, and salivin of the gastric juice, pancreatic fluid and saliva, and the mucin of the mucous glands. The three former substances are, by some, regarded as examples of albuminoid compound undergoing retrograde chemical changes, or in peculiar states of hydration. In other cases, the substances formed by secreting glands, though more remote in chemical constitution from that of the materials of the blood, and not pre-existent in it, are of a highly complex nature, and are only partially reduced or oxidized substances, such as the tauro- and glyco-cholic acids of the bile, the butyrin of the milk, and the fat of the sebaceous secretion. Extreme examples of special secretive power, by which compounds not existing in the blood, are formed from it, are afforded by the appearance of sulphocyanogen in the saliva, and of hydrochloric acid in the gastric juice. So, also, soda is withdrawn from the normal soda salts of the blood, by the agency of the liver, to combine with the fatty acids of the bile.

In the case of the *excretions*, however, the characteristic substances eliminated from the blood pre-exist in that fluid, as the result of decomposition, and are always much more chemically reduced by oxidation than any product of secretion, or they are even completely oxidized. They usually exhibit a comparatively simple atomic constitution, are often crystallizable, and frequently take the form of bases or acids, such as the lactic and uric acids, and the urea, formed in the urine, together with the sulphates and phosphates resulting from the oxidation of the albuminoid constituents of the body; such also as the lactate of ammonia, and the acetic and formic acids of the cutaneous excretion; and lastly, the perfectly oxidized carbonic acid, given off in small quantities by the skin, but forming the characteristic product excreted by the lungs. Such substances are manifestly incapable of animal organization. They are even, if retained in the system, noxious, or fatal. The purpose of excretion is, indeed, to rid the body of the compounds which are formed during the action of the living tissues, by the oxidation of their substance, or of the blood passing through them. The successive stages of oxidation render such compounds more and more removed from an organizable character, and necessitate their removal.

In all the secretions, if one excepts the peculiar albuminoid substances, the saline substances and other special compounds are either crystallizable, such as the sulphocyanide of potassium in the saliva, the soda salts of the biliary acids, and the lactin or sugar of the milk, or crystalloid, such as the hydrochloric acid, and other acids in the gastric juice. All these would freely dialyze from the blood, or from the secreting cells. As to the modified albuminoid substances, which are colloidal, such as salivin, pepsin, pancreatin, and casein, it is possible that the secreting cells may themselves burst, and yield up their albuminoid contents; or the secretion of such substances from the blood may present us with examples of the metastasis of colloidal substances from the pectous to the liquid, or from the liquid to the pectous state, as occasion may require.

In the process of excretion, it is, as already mentioned, the highly diffusible crystalloids alone, which escape from the blood, so that it may more readily be referred to a pure dialysis, the one condition necessary, say, in the secretion of urea, *e. g.*, being a special chemical relation between the dialyzing epithelial cells and the dialyzable urea, which serves to locate the excretion of that substance in the kidney.

In the formation of living vegetable tissues, crystalloids, such as ammonia, carbonic acid, and water, are converted into colloids, and the further processes of organization, up to the final and highest nutritive stage, require various metastases of these colloids. In the downward step of disintegration and disorganization, materials are formed which are to be excreted, and then the crystalloid condition of matter again prevails, as in the urea and uric acid thrown off by the kidneys, which easily pass into ammonia, and the carbonic acid and water of the cutaneous and pulmonary exhalations.

The general forms of the secreting and excreting glands, and the mode in which those forms may be derived from the involution of a simple secreting membrane, have already been described (p. 64). In all cases, there is invariably found, even in the ultimate ramifications of the gland ducts, a limiting or basement-membrane covered by a stratum of epithelial cells. All glands are, moreover, very vascular, and receive large quantities of blood. The special secretions and excretions are the products or educts of special organs. The most essential modifications of the anatomical gland-elements are those which relate to the epithelial cells. In secretion proper, these important elements are frequently dissolved or ruptured, and their contents, if not their envelopes, escape as part, perhaps an essential part, of the secretion itself, as in the case of the saliva, pancreatic fluid, gastric juice, and milk, and of the sebaceous and the mucous secretions, and also, perhaps, of the bile. But in the case of the lachrymal secretion, and in the excretory processes generally, this is not so; for the epithelial cells in the ducts of the kidney, the lachrymal gland, and the sweat-glands, and also, it may be added, in the air-cells of the lungs, merely withdraw, as it were, by a special attraction, certain products already pre-existing in the blood, and part with them again, into the ducts or canals, which convey them out from the body, without themselves undergoing any necessary dissolution or decay.

The liver receives a peculiar venous blood, loaded with the products of the venous absorption of the food, and with those which enter the blood of the spleen; but, with this exception, the cause of the differences between the several secretions, cannot depend on the character of the blood distributed to the respective glands, which is uniformly pure arterial blood. Neither can it depend upon the number or arrangement of the capillary vessels, for these peculiarities can only determine the quantity, not the quality, of a given secretion. Nor is there any evidence to show that the walls of the capillaries differ in different glands, nor even the basement or limiting membrane, which always presents a glass-like, structureless, appearance. Again, the relative simplicity, or complexity, of a gland cannot be supposed, in any way, to determine the character of its secretion; for, though differently formed glands, supplied by the same blood, often yield different secretions, yet there are cases, in which very similarly formed glands produce different secretions, as, for example, the salivary, pancreatic, and mammary glands. Moreover, on regarding the Animal Kingdom generally, it is found that similar secretions, as, *e. g.*, the bile, the gastric secretion, and indeed nearly all the secretions, are formed, in different cases, by glands of variable structure, sometimes complex, sometimes simple, according to the position of the animal in the scale of organization. There is one component, however, of all secreting and excreting organs, whether membranous or glandular, viz., the epithelial layer, which appears to be essential to specific secretion, and to be the seat of the selective *assimilative* power of the true secreting glands, and of the selective *eliminative* power in the excretory glands. The epithelial cells of different membranes and glands, most frequently present differences of structure and arrangement, suggestive of the possession of different properties. The peptic and hepatic cells, the columnar cells of the intestinal tubuli, and the cells of the sebaceous cutaneous glands, are totally different from each other. Even in the simplest glands in animals, as in the so-called hepatic tubuli, special epithelial cells are discernible. Epithelial cells are components of the solid texture of the body, subject to the ordinary processes of development, growth, and nutrition; but they are distinguished by a peculiar destiny or purpose in the economy, and to them we must refer that special form of nutrition, which, instead of resulting in the development or maintenance of a tissue, destined for certain mechanical or vital purposes in the animal framework, is employed for the formation, or separation, of more or less liquid products, intended for digestive or other uses, or destined to be eliminated, and entirely discharged, from the system.

Most frequently, the gland-cells effect changes in the materials which are presented to them by the blood; but, at other times, they attract from that fluid compounds which pre-exist in it. In either case, it is these cells which attract or separate the *products* or *educts* from the circulating fluid.

The *general conditions* which influence the functions of secretion and excretion, are the quantity of blood supplied to the respective glands, the quality of that blood, the presence of external stimuli, acting directly or indirectly on the nerves, and, perhaps, some governing influence of the nervous system itself.

As a rule, an increased *quantity of blood* supplied to a gland, determines an increase in the amount of its secretion, as is illustrated by the increased redness of the gastric mucous membrane observed in the case of the Canadian voyageur, Alexis St. Martin, during the active secretion of the gastric juice, and by the increased vascular turgescence of the mammary gland during lactation. As in ordinary nutrition, however, the secretive demand, implied by an increased secretive act, precedes the actual flow of additional blood to a given gland.

The influence of *quality in the blood*, is perhaps greater in regard to the excreting than to the secreting glands, as might, indeed, be expected. The presence of a greater or less quantity of the special materials to be separated and eliminated from the blood, must have a direct effect. An excess of urea or uric acid in the blood, whatever may be its cause, determines an increased elimination of those products from the kidneys, and an increased consumption of water, augments the quantity of the renal excretion. A temporary increase of carbonic acid in the blood, owing to the rapid oxidation of combustible substances, is followed by an increased evolution of that gas from the lungs; whilst the drinking of water augments the pulmonary exhalation and the cutaneous transpiration. The various secretions are also modified in quantity, by the amount of fluid absorbed from the stomach; and the relative amount of their characteristic ingredients, is dependent on the existence of certain proportions of particular blood constituents from which they are derived, as seen in the production of the fatty acids of the bile, and of the sugar, and the peculiar fatty acids of the milk.

The effects of *stimuli* are chiefly to be noticed as influencing the quantity of a given secretion, as in the case of a flow of tears, induced by a foreign body irritating the conjunctiva, or of saliva, from the action of vinegar, mustard, or salt. Stimuli act probably through the intermediation of the vasi-motor nerves, either directly, or else by reflex action, through other nerves and nervous centres with which the vasi-motor nerves are connected. The general effect of such stimuli is to dilate the small arteries of the gland; a corresponding increase then occurs in the flow of blood to it, and is the proximate cause of an increased secretion or excretion. This increase may, as in the case of the saliva, augment the quantity, but not improve the quality of the secretion, which becomes more watery than usual.

There are many facts which show an intimate relation between the *nervous system*, and the secreting activity of the several glands. Thus, the emotions often determine increased secretion, as, *e. g.*, from the lachrymal glands, the skin, the alimentary mucous membrane, and the kidneys. The sight, or even the idea of food, will excite the flow of saliva. Extreme passion or grief has been known to modify, or even render poisonous, the mammary secretion. Direct experiments also show most remarkable effects produced upon the secretive process, through the nervous system, as illustrated in regard to the salivary glands (pp. 264, 522), the gastric glands (p. 526), and the liver (p. 748).

All glands are provided with sympathetic nerves, and many, if not all, possess others derived from the cerebro-spinal nervous system. The experiments just referred to, show that the *quantity* of a secretion is differently affected by the section, or irritation of these two sets of nerves. Thus, irritation of the pneumogastric nerves, increases the quantity of the gastric juice, whilst irritation of the sympathetic nerves, diminishes or arrests it. Again, division of the sympathetic nerves of the submaxillary gland, increases the flow of saliva, but irritation of the distal cut portion of the nerve, diminishes it; on the other hand, section of the cerebral nerve diminishes, whilst irritation of the distal cut end, augments it. Even simple irritation of the undivided sympathetic nerves causes diminution, whilst a similar irritation of the undivided cerebral nerve, causes an increase of the secretion. Since, in the former case, the small arteries of the gland contract, and the supply of blood is diminished, whilst in the latter, those vessels dilate, and more blood is distributed to the gland, the diminution or augmentation of the secretion accords, in either case, with differences in the quantity of blood conveyed to the gland, and the influence of the nervous system in regulating the quantity of the secretion, is indirectly manifested by the dilatation or contraction of the coats of the small arteries.

With regard to the influence of the nerves on the quality of a secretion, it is found that when the arteries are contracted, and the supply of arterial blood lessened, not only is the quantity of saliva diminished, but the color of the venous blood returning from the gland is, as usual, dark; whereas, when the arteries are dilated, the supply of blood is increased, and the amount of secretion augmented, then the color of the returning venous blood is bright. In the former case, the passage of the blood through the gland seems to be sufficiently deliberate to permit of the proper nutritive or secretive interchanges between it and the epithelial cells; whilst in the latter case, the blood flows so rapidly through the glands as not to undergo these changes. It is not proved that the sympathetic nerve determines, or even increases the secreting power of the gland.

By controlling the quantity and velocity of blood passing through a gland, the sympathetic nerves may, therefore, not directly, but indirectly, by permitting the characteristic function of the gland, preserve the essential *qualities* of its secretion; whilst, on the other hand, the cerebro-spinal nerves, by determining an increased supply and quicker motion of the blood, must, by partially interfering with, or overwhelming the special actions of the secreting cells, increase the fluid in the secretion, but so dilute and lower its qualities.

Whilst it is not yet proved that either the sympathetic or the cerebro-spinal, nervous system has any power over the chemical acts of secretion, independently of their governing influence over the bloodvessels, it must be added that this is a point on which opinions are at variance. As already remarked (p. 705), if, as it seems scarcely possible to doubt, the nervous system influences the secreting processes in such of the lower animals as are unprovided with bloodvessels, and yet possess nerves, it is difficult to deny the existence of some such direct influence in the higher vascular animals and in Man, however unintelligible the nature of such a controlling process may be.

Whatever the influence of the nervous system upon secretion, it may be centric, or peripheral, and either simple or reflex, according to the part in which the stimulus originates, or to which it is applied. Tears are shed, and saliva flows, under the centric stimulation of painful or joyous emotions, and on the occurrence of ideas relating to food; whilst the same secretive acts are performed under reflex action, from neuralgia of the fifth cerebral nerve, or from local irritation of the conjunctiva or of the mouth.

When, either from disease of the glands, or from an over-accumulation, in the blood, of the materials to be excreted, these are no longer eliminated through the usual organs, they are sometimes vicariously eliminated through some other gland or membrane. Thus, urea has been found in almost every secretion and excretion of the body, in the gastric and intestinal discharges, in the lachrymal and salivary fluids, in the nasal mucus, in the synovial and serous fluids, the perspiration, and even in the milk. The pigment of the bile, which is probably more of an excretory than a secretory product, occasionally appears in the renal excretion and in other fluids of the body. These are instances of real vicarious excretion, but in regard to the secretions proper, no such metastasis, or transference, of secreting power has been observed, no authentic example of milk secreted by the liver or kidneys, or of saliva formed by the mammary gland, having yet been met with. The presence of the coloring matter of the bile in various true secretions, as in the pancreatic juice, the milk, the mucus of the bronchial glands and membrane, and even in the serous and synovial fluids, is perhaps only an apparent example of vicarious secretion; for, in these cases, the coloring matter of the bile is probably reabsorbed into the blood, and then is simply exuded into all parts of the body with the common nutrient plasma, and so tinges the various solid tissues, organs, glands, and secretions. There is, moreover, no evidence that, even in these cases, the more abundant and truly secretory products of the hepatic cell action, viz., the soda salts of the biliary acids, accompany the bile pigment in its passage through the body, or into the secretions of other glands. The biliary pigment probably represents an excretory part of the bile, and, if not preformed in the blood, is easily dissolved and taken up by it, and thus it may obey a true metastasis like other excretory substances. It certainly appears very readily in the urine, and also sometimes in the perspiration.

Certain excretions are complementary to each other, as, for example, those of the lungs and the liver. The more abundant the excretion of carbon in its perfectly oxidized form of carbonic acid gas from the lungs, the smaller is the amount of carbonaceous compounds excreted in the bile; whilst, on the other hand, when the respiratory changes are diminished through heat of climate, or defective exercise, the biliary products are increased. The excretions of the skin and the kidneys, are also, to a certain extent, complementary to each other, not only as regards their aqueous constituents, in respect of which, each is, moreover, supplemented by the lungs, which give off more or less vapor according to the relative degree of the moisture of the air, but also in regard to some of the products of oxidation of the albuminoid tissues, viz., urea, ammonia, and carbonic acid.

Different secretions and excretions differ as to the time at which they are prepared. Some are constantly or continuously formed, whilst others are secreted, or excreted, intermittently, or remittently. Secretions are more commonly intermittent or remittent, serving occasional purposes in the economy, as, *e. g.*, the gastric juice, the secretion of which is probably limited to the period of digestion, and the lachrymal, salivary, hepatic, pancreatic, and mammary secretions, which are always being secreted in small quantities, but are, from time to time, as required, produced in much larger amounts. On the other hand, the excretions being injurious, and requiring to be eliminated as rapidly as possible from the blood, are characterized by their constant separation, both day and night, the process varying in activity, however, according to circumstances.

The *force* by which the secretions are urged along the ducts, is probably the vis à tergo, dependent upon the pressure of continuously fresh-formed portions of fluid secreted in the commencing ducts. The movement in the larger ducts is aided by the slow contraction of the organic muscular fibres in the walls of the ducts. In some cases, as in the bile and pancreatic ducts, and the ureters, rhythmic movements have been seen, and in others, peristaltic movements. The pressure on the fluid in the ducts is sometimes considerable, as is seen by the occasional ejaculation of the saliva, and the expulsion of the milk. The action of the surrounding muscles must, here and elsewhere, also be taken into account. In certain cases, the larger ducts are dilated, near their mouths, into temporary receptacles for the secretion, as is seen in the parotid and lactiferous ducts. Still more special developments of the excretory apparatus are met with in the shape of reservoirs or bladders, with contractile walls, when as in the case of the bile, the secretion is abundant and used intermittently, or when, for other reasons, an excretion requires to be retained, and only occasionally expelled.

The daily quantities of the various secretions and excretions, as stated elsewhere in the account of each, differ remarkably in different individuals, and in the same individual under different circumstances. The quantities of the excretions, in health, conform to the quantity of water taken in the solid and fluid food, one of the objects of this elimination of water, being to maintain the due characters of the blood. In the formation of the extraordinary quantities of the secretions employed in the digestive process, the water concerned is, as already mentioned, separated from the blood, used in dissolving the food, reabsorbed, and re-secreted many times over.

The preceding facts and considerations illustrate the general resemblances and differences between nutrition and secretion. In both processes, the blood yields a common plasma to certain organs; from this plasma, in both, materials are attracted by a selective property possessed by pre-existing tissue elements; and, in both, the residual and altered plasma re-enters the blood. But this difference arises: in the one, the separated materials form an intrinsic part of a solid and more or less permanent tissue, and enter into the coherent framework of the body; whereas, in the other, whilst a part thus remains to form the gland-tissue itself, the essential products are discharged, in the fluid state, by ducts, and are applied extrinsically to special functions of the economy, sometimes, however, being then reabsorbed into the blood. Both the nutritive and the secretive process yields various results, according to the tissue in which they occur; nutrition forms nerve, muscle, or bone, and secretion, saliva, pancreatic juice, or milk, according to the nature of the tissue-elements which select, or determine, the separation of the nutrient or secreted materials from the blood plasma. Both nutrition and secretion are modified by the quantity and quality of the blood, and by the reactions of the vasi-motor nerves. The nutritive and secretive processes may both be either continuous or intermittent, the former being illustrated by the continuous formation of the epidermis and of mucus, and the latter by the intermittent nutrition of the muscular and nervous tissues and the formation of the gastric juice. Lastly, the two processes resemble each other, in being more active in some parts than in others, being more so in the heart, the nervous centres, and the salivary glands and sweat glands, than in the tendons, cartilages, bones, and the mucous and sebaceous glands.

SPECIAL SECRETIONS.

Most of the secreting glands and their products have already been considered, viz., the lachrymal glands and the tears, with the appendages of the eyes; the nasal glands, with the organ of smell; the ceruminous glands, with the ear; the sebaceous glands, with the skin; and, lastly, the mucous glands of the mouth, fauces, pharynx, œsophagus, stomach, and duodenum, the saliva and salivary glands, the gastric and intestinal tubuli and their secretions, the liver and pancreas and their respective products—with the organs and function of Digestion. The tracheal and bronchial mucous glands will be mentioned hereafter, in the Section on Respiration. There remain, however, certain general considerations concerning the liver and its offices, which may be here noticed; whilst the mammary glands with the function of *lactation*, and the mucous, serous, and synovial secretions, also require description.

Secreting Function of the Liver.

The source of the bile secreted by the hepatic cells is the exuded plasma of the portal blood, which, however, is joined by the blood from the nutrient capillaries of the liver, derived from the hepatic arteries. That the portal blood is essential, and the arterial blood non-essential as such, to the formation of bile, is proved by the facts, that when the portal vein is compressed, the quantity of bile is diminished, and that when it is tied, bile is no longer secreted; whereas, if the hepatic arteries be tied, its secretion is not necessarily arrested. (Schiff.) In certain cases of malformation, the portal vein has been found to open into the inferior vena cava, and yet bile has been secreted. Hence the portal blood has been held to be non-essential to the formation of bile; but, in such cases, the umbilical vein is permeable, and sends branches through the liver; moreover, the blood of the hepatic arteries, having first become venous, may enter the lobular plexuses, and so secrete the bile.

That the biliary acids are not preformed in the blood, but are elaborated in the hepatic cells, is shown by extirpating the liver in frogs; these animals then survive for some days, and yet no trace of the fatty acids of the bile is found in the blood, which would be the case, if the bile were preformed in, and merely separated as an educt from, that fluid. The green coloring matter, and also cholesterin, may, however, pre-exist in the blood. The cholic acid may be derived from the fats of the blood, whilst the taurin and glycocoll, which are conjugated with it, the former containing both sulphur and nitrogen, and the latter only nitrogen, probably arise from the decomposition of albuminoid substances. The coloring principles may be formed from the cruorin, or coloring matter of the blood, which they closely resemble. Animals fed on fat, have been said to secrete proportionally more bile; but this is denied, and the quantity of albuminoid food consumed, seems rather to regulate the amount of this secretion.

Besides its office in digesting fat, and stimulating the muscular acts concerned in digestion and absorption, the bile has other uses. The fatty acids, largely reabsorbed, may become converted, in the circulation, into carbonic acid and water, for respiratory, motor, and calorific purposes. The glycocoll, taurin, and the coloring matters are apparently excreted. The glycocoll is probably thrown off by the kidneys as urea, for when it is administered as food, more urea is then eliminated; the coloring matters, altered from a yellow to a greenish, and then to a dark-brown hue, some taurin, and likewise a small portion of the cholic acid, converted into dyalysin, are found amongst the excreta. The excrementitious character of the bile is further indicated by the size and activity of the liver before birth, when no digestion is going on. Moreover, by its glycogenic function, the liver performs a highly important nutritive office, affording to the body respiratory food. Lastly, it may be said to act as a purifying agent on the venous blood returning from the alimentary canal, partly by its direct power of assimilating albuminoid, oleaginous, saccharine, and coloring substances, but also partly as a sort of filtering organ, in which foreign bodies, such as metallic salts and other substances, are detained, and prevented from entering too suddenly into the general circulation.

Irritation, or division, of the pneumogastric nerves, below the diaphragm, appears to produce no effect on the quantity of the bile secreted in a given time; but injury to both, or even to one of those nerves higher up, interferes with the biliary secretion, perhaps by its effect on the circulation and respiration.

When the bile is not eliminated from the system, or when it is reabsorbed, symptoms of nervous prostration ensue, with headache and jaundice, often followed by death. The constituents of the blood, out of which the bile is formed, when retained, or the bile itself when taken up, appear, therefore, to be noxious, or even poisonous.

The combined assimilative, secreting, excreting, and purifying actions of the liver, are consistent with its large size, its general presence in nearly all animals, its marked vascularity, the peculiar source of its blood, the high temperature of its tissue and of the hepatic blood returning from it, and the singular variety of the metamorphic changes which take place in it. So long as its office was supposed to be merely to secrete 2 oz. of solid *biliary matter* daily, whilst the lungs excrete 8 oz. of *carbon* in the same time, the size and other characters of this gland were not fully explained, especially in its embryo state; but its glycogenic function, and its influence in the process of sanguification, sufficiently account for its pre-eminence amongst all the glandular organs of the body.

The Mammary Glands and Lactation.

The human infant, and the young of all *Mammalia*, are supplied with suitable nutriment for the first months of their existence, in the well-known fluid named *milk*, secreted by the *mammary* glands. It is in the female only that these glands yield milk, the process being termed *lactation*. In the males of mammiferous animals, these glands exist, but their parts are very small.

The mammary gland, in woman, is a large organ, composed of numerous lobes, arranged, in a more or less radiating manner, around the projecting part, named the *mammilla*, or *nipple*. The lobes, which may be moved slightly upon each other, are separated by fibrous septa, and are held together by a general investment, stronger on the under side of the gland, where it rests upon the pectoral muscle. Each lobe consists of a number of lobules, possessing the structure of a compound racemose gland, closely resembling that of the parotid gland (Fig. 42, *c*). The terminal ducts end in clusters of short follicles, or vesicles, about $\frac{1}{200}$th of an inch in diameter, which, when filled, are just visible to the naked eye, and the walls of which are lined with a layer of soft glandular epithelial cells. From these follicles, the smallest lactiferous ducts unite into one or more larger ducts for each lobule, and these join into still larger tubes, called *galactopherous* ducts, one or more for each lobe. These large ducts, about fifteen in number, run to the centre of the gland, and generally dilate, so as to form temporary receptacles for the milk. The walls of these ducts are composed of a fibrous coat, containing unstriped muscular fibres, and lined by a mucous membrane continuous with the skin. They open at the summit of the nipple, by separate small round orifices, seen at the bottom of little depressions in the skin. The arteries of the mammary gland are numerous, and proceed from many sources; they present a good example of the enlargement of bloodvessels supplying a part in which increased activity of function occurs. Numerous capillaries surround the terminal vesicles of the gland. The veins and lymphatics are also numerous. So likewise are the nerves, partly spinal and partly sympathetic, the latter reaching the gland along the arteries.

The first secretion of milk is preceded by an enlargement of these glands, which causes a certain hardness and tenderness of the part and a febrile disturbance of the system, known as *milk fever*. The first milk secreted, much thicker and darker than the subsequent secretion, is named the *colostrum*. After lactation is established the secretion is not uniform but remittent, proceeding slowly during the intervals of sucking, so as not usually to accumulate and cause suffering, but suddenly increasing, in accordance with the great afflux of blood to the glands during the act of nursing. The fulness and increased secretion experienced at this time constitute the phenomenon called the *draught*. From each distended gland the quantity obtainable by pressure is about two ounces, but the daily quantity secreted by both fluctuates according to so many circumstances that no correct average is attainable. The composition of the milk also varies exceedingly. Its specific gravity ranges from 1030 or less, to 1035. The color of human milk is bluish-white, owing to its greater transparency as compared with cow's milk. It is opalescent, and perhaps fluorescent. It contains from 860 to 910 parts of water in 1000, the solid matter varying accordingly from 14 to 9 per cent.; its average composition is 89 parts of water to 11 of solid constituents. These latter consist of 4.5 of lactin or sugar of milk, 3.5 of casein, 2.5 of fatty matters or butter, .3 of extractives, and .2 of alkaline and earthy salts, together with traces of iron. Milk likewise contains, like the blood, carbonic acid gas, nitrogen, and oxygen, the total amount of these gases being about 3 per cent. of its volume; more than half of this is carbonic acid gas, and only $\frac{1}{25}$th part oxygen, the remainder being nitrogen.

The milk is a true secretion, formed out of the materials of the exuded plasma of the blood, by the agency of the epithelial cells of the terminal vesicles of the gland. It is composed of a slightly turbid fluid, containing suspended in it a vast number of minute, more or less spherical particles, named the *milk globules;* these are composed of an oily matter, surrounded by a thin film or pellicle of albuminoid substance, probably of casein, for neither ether nor an alkali, which would dissolve fatty matter, attacks them, unless they are first acted on by acetic acid, or are strongly agitated, so as to dissolve or break the albuminoid film, which does not appear to be organized. These milk globules vary from $\frac{1}{12000}$th to $\frac{1}{3000}$th of an inch in diameter; other and much smaller spherical particles, manifesting the molecular movement, exist in the fluid, and probably cause its turbidity; some of these may consist of casein, but they are chiefly fatty, and readily dissolve in ether. The milk also contains a few epithelial cells from the ducts. Owing to the thin pellicle around the milk globules, these do not at once run together, but only coalesce, after a time, in the formation of the cream. In the colostrum the milk globules are very minute, but there also exist in it peculiar large, yellowish, closely and finely granular fatty corpuscles, which resemble the so-called exudation cells, or compound inflammation cells; these appear to result from the fatty degeneration or transformation of the glandular epithelial cells. The colostrum contains albumen, or at least it coagulates on boiling; it also has a larger proportion of sugar and saline constituents. It exercises an aperient effect upon the new-born infant. The colostric condition sometimes persists for too long a period, and then the milk is less suitable for food.

As long ago remarked by Prout, milk presents us with a type or pattern of food, for it contains, in definite and duly balanced proportions, nitrogenous and non-nitrogenous nutrient substances, albuminoid, fatty and saccharine, fitted for both plastic and respiratory purposes, and, besides these, suitable salts for the blood and tissues. Milk, as we have seen, is composed of water which holds in *solution* lactin or milk-sugar, casein or the albuminoid substance characteristic of this secretion, certain extractive matters and salts; whilst it contains, in suspension, fatty with albuminoid matter. When set aside in quantity, a natural analysis of milk takes place; first, the oily matter, being of light specific gravity, together with a certain amount of casein, and even sugar and saline substances, rises as *cream*, the globules of which, by agitation, as in the process of churning, combines to form *butter*, leaving most of the casein, the sugar, and other substances, extractives, and salts, in the *buttermilk*. After a time, some of the sugar in this buttermilk undergoes a peculiar fermentation, perhaps excited by the casein, and is changed into *lactic acid;* this immediately precipitates the casein in minute flocculi, which combines to form the so-called *curd*. The residual fluid, called the *whey*, now contains most of the lactin or sugar of milk, with lactic acid, extractives, and salts.

The fatty matter of the cream consists chiefly of olein, but it also contains stearin, and, in particular, a peculiar fat, named butyrin, which is a compound of butyric acid and glycerin, and imparts to butter its characteristic taste and smell. It yields, when acted on by alkalies, and also when spontaneously decomposed at high temperatures, besides butyric, small quantities of caproic and capric acids. The casein of human milk is not so easily precipitated by acids or by rennet, as the casein of cow's milk; in this respect, and also as regards its smaller quantity of casein, human milk resembles more closely the milk of the ass. The lactin or sugar of milk, which may be separated by crystallization from inspissated whey, is convertible into grape-sugar, by dilute mineral, or by vegetable, acids; it is very prone to enter into the lactic fermentation, and even to form butyric acid by decomposition; but it is difficult to transform it into alcohol. The extractives of milk have not been well examined. The salts resemble those of the blood; but they present curiously a larger relative amount of the earthy phosphates of lime and magnesia, which are combined with, and rendered soluble by, the casein. Chlorides of sodium and potassium, and traces of phosphate of iron, are met with. Human milk may be either neutral, alkaline, or acid; but the milk of most animals usually, and that of the Carnivora always, at the time of its examination, is acid, from the presence of free lactic acid.

The casein is probably formed by the secreting power of the mammary gland cells, from the albuminoid principles of the blood; but, according to some, it is preformed in the blood itself during the period of lactation. It supplies materials to the infant for the re-formation of albuminoid compounds. The oily matters derived from the animal fats, or from sugar, and the sugar itself, the source of which is yet unknown, are not only directly adapted for respiratory purposes, and the production of animal motion and heat in the infant, but also, as well as the casein, are doubtless employed, in part, in various important nutritive and secretive processes. The salts of the milk are also those which are essential to the formation of blood, salts of potassium and iron for the corpuscles, and salts of soda, calcium, and magnesium for the liquor sanguinis. The phosphates of lime and magnesia are absolutely necessary for the growth of the young skeleton. Of all the secretions milk is especially nutritive, and most closely resembles blood in composition, its chief distinction from that fluid being the large quantity of sugar in it. Milk alone contains albuminoid, fatty, and saccharine elements combined. Its secretion is not essential to the system, being, ordinarily, limited to one sex, and, in that, being temporary or periodic. From its general resemblance to blood, the arrest of its secretion is not so pernicious as the non-secretion of the bile; nevertheless, its retention within the gland, besides causing obstruction of the ducts, inflammation of the organ, and its consequences, may likewise, perhaps, prove injurious through reabsorption, especially of the crystalloids, lactin, and lactic acid. It has been supposed that its constituents may be retained in the blood, and so account for the constitutional disturbance which follows the sudden arrest of the secretion; but the proper constituents of the milk are probably not, normally, pre-existent in the blood, though they may, like those of other secretions, be reabsorbed. Cases of vicarious secretion of milk, which are very numerous, may depend on reabsorption, and distant exudation, of the absorbed constituents. A case has been recorded of the expectoration of milk following sudden arrest of the secretion. Instances of so-called vicarious secretion of milk from the inguinal region, have been supposed to be due to the presence of supernumerary mammary glands in that position. This would correspond with the normal situation of these glands in some of the lower animals, and rudiments of more than one pair of mammary glands are sometimes met with in the human body.

The quantity and quality of the human milk vary according to many circumstances. Thus, it is not only most abundant, but most nutritious, in nursing women, from the age of 15 to 20, whilst it is least so, in those from 35 to 40. The constitution also greatly influences the character and nutritive qualities of the milk; hence the necessity for the selection of healthy wet-nurses. In the early periods of lactation, the casein is at first relatively small in quantity, but afterwards becomes increased and attains a determinate ratio; whilst the sugar is at first abundant, but afterwards reduced in proportion. From experiments on the cow, the fatty matters seem to vary most, chiefly according to the nature and quantity of the food, the temperature in which the animal lives, and the amount of exercise it is permitted to take. Thus, warmth and rest, increase the quantity of oily matter, whilst cold and exercise diminish it. (Playfair.) Exercise, however, increases the relative amount of casein. Both in the human subject and in animals, the nature of the food, and the quantity of water taken in, or with it, must directly influence the specific gravity, the amount of solid matter, and the relative quantities of the several ingredients of the milk. It has been observed in the cow, that the last milk drawn, at any one time of milking, is richer than the first.

The influence of the nervous system in modifying the quantity and quality of the milk, is most important, and universally recognized. Irritation of the nipple increases, by a reflex influence, the flow of milk; this is probably one cause of the rapid flow of the secretion during the act of suckling. Continued local irritation, combined with a strong desire for the occurrence of lactation, and a fixed attention towards the mammary glands, have been known to produce this secretion in women not recently mothers, to protract its flow for many years, to excite it in aged women and in girls, and even, it is said, in individuals of the male sex. In that sex, usually, however, the rudimentary glands yield only occasionally, a thin clear fluid, the composition of which is uncertain. The influence of the nervous system, as affected by mental states, upon the secretion of the milk, is further evinced by the abundant flow, the so-called draught, often excited by the sight, or even by thinking of the infant. Tranquil and pleasing emotions favor the normal secretion; but anger, anxiety, grief, and terror may produce serious modifications in the quality of the milk, or may even suspend its formation. Violent passions may induce such changes in this secretion, as to cause it to be poisonous, and even immediately fatal to the infant. This probably arises from some modification in the blood (p. 732).

To secure the healthy performance of the function of lactation, an ample amount of nutritious food, moderate exercise, tranquillity of mind, and regular habits, are necessary conditions; a defective or excessive diet, fatigue, and irregularities and excesses of all kinds, are unfavorable. The influence of alcoholic stimulants, in moderation, is, by promoting digestion indirectly, favorable to the supply of milk. Medicinal agents, especially those of a powerful kind, should be avoided; many of them enter the milk, and may thus affect the child. Mineral and saline substances, and the alkaloids, such as quinine and morphia, pass more readily into the milk than vegetable aperients.

The peculiarities in the milk of the cow and other animals, as compared with human milk, are interesting in a dietetic and economic point of view:

	Woman (Simon)	Cow (Simon)	Goat (Chevalier)	Sheep (Chevalier)	Ass (Simon)	Mare (Luciscus)
Water, ...	890	860	868	856	907	888
Solid matters, ...	110	140	132	144	95	112
Butter, ...	25	38	33	42	12	8
Casein, ...	35	68	40	45	16	16
Sugar, with extractives, .	48	30	53	50	65	88
Salts, ...	2	6	6	7		

According to this Table, the milk of the *goat* more closely resembles, in chemical composition, the human milk than does that of any other animal; but it has been found that, besides having a peculiar odor, its curd is remarkably compact. The milk of the *sheep* differs a little more from human milk.

That of the mare and of the ass, are characterized by the small quantity of butter and casein, and the large quantity of sugar which they contain. The milk of the mare is most remarkable for its enormous proportion of sugar; this may explain its disposition to undergo the alcoholic fermentation, a fact turned to account by many Tartar tribes, in order to make an intoxicating drink. The milk of the ass, notwithstanding its difference from human milk, is, perhaps from the difficulty with which its casein is precipitated, and from the delicacy of its curd, the most easily digested by the human infant. Cow's milk, which is the great source of milk for human food and the great substitute for human milk in the case of infants, contains more casein and more butter than human milk, but only about 3-5ths of the quantity of sugar. The specific gravity of good milk is about 1030, that of the cream being 1024, and that of the skimmed milk about 1035; by means of a proper lactometer, the quality of milk may be determined approximately by every householder. Considered as infant food, the milk of the cow is too rich in casein and butter, and too poor in sugar; hence it should be diluted and sweetened, either with common white sugar, or, what is better, with sugar of milk. Half a pint (imperial) of good fresh cow's milk, with half an ounce of milk-sugar and half a pint of water, will form a tolerably near approximation to ordinary human milk, but it is deficient in the due proportion of saline, earthy, and ferruginous salts. As an infant advances in age, the sugar and water may be diminished, and farinaceous food may be added. It is well known that the milk of certain breeds of cattle, is richer than that of others. Authorities differ as to the relative richness of the milk of cows fed in town dairies or country pastures, but country milk must be more natural, and better as food, than the artificially forced production of the town-fed animal, other circumstances being equal.

The mammary glands, as is well known, differ in arrangement and position in different orders of Mammalia; sometimes, as in the Carnivora and in the pig, they are divided into numerous portions, disposed along nearly the whole length of the under side of the trunk, each symmetrical mass having its own nipple; sometimes, as in the Ruminants, and in the genus Equus, they are post-abdominal; in the Cetacea, they are situated even still further back; in the Quadrumana, as in Man, they are found in the pectoral or thoracic region only. The microscopic structure resembles that of the human gland, excepting in the lowly organized Monotrematous ornithorynchus, in which the milk glands consist merely of clusters of simple blind follicles, opening in a group on the skin. This simple structure suggests an homologous relation between the mammary and the cutaneous gland.

Mucous Secretion and Mucus.

Mucus is the clear, or slightly turbid, colorless, viscid fluid found on mucous membranes. It is partly secreted by the epithelial cells of the compound racemose glands, but in part, also, by those of the surface of such membranes. It is a special secretion from the plasma of the blood, and differs from it chemically. Mucus is commonly alkaline, but often speedily becomes acid; normally, perhaps, it is neutral. It is composed chiefly of water, holding in it from 4 to 6 per cent. of solids. It contains desquamated epithelial cells, mucous corpuscles which closely resemble the white blood corpuscles, and pus corpuscles, and also certain nucleated cells intermediate between the true mucous cells and epithelial cells. Its chief constituent is a special albuminoid substance, called *mucin*, which, precipitable by alcohol, acetic and other acids, but not by boiling, swells up, rather than dissolves, in water, and is the cause of its natural viscidity; besides this, it contains a small amount of extractives, and salts like those of the blood. It is sometimes very thin, as when secreted from the nose during a cold; in other situations, it is much more viscid, as the intestinal or vesical mucus, and the nasal mucus; that from the air-passages in cases of cold is very viscid, and contains albumen. The use of mucus is chiefly mechanical, assisting in the acts of mastication, deglutition, or speech, or, as in certain animals, in the capture of prey. It aids in taste and smell, preserving the moisture of the parts, and acting also as a solvent. It is likewise protective, both mechanically and chemically, by offering resistance to the action of the digestive fluids, which do not easily dissolve it. Sometimes it behaves as a ferment, possibly assisting the salivin, pepsin, and pancreatin, though not possessing very active powers. It, or something mixed with it, undoubtedly determines the retrograde decomposition of the renal excretion, when this is retained longer than usual in the body. Mucin, not being readily soluble or digestible, cannot, strictly speaking, be nutritive or absorbable.

Serous and Synovial Secretions.

These fluids, which cover and moisten the surface of the serous and synovial membranes, differ so little in composition from the plasma of the blood, that their formation has by some been regarded, not as a process of secretion, but as one of transudation through those membranes. A certain modification of the plasma of the blood, as it is exuded from the capillaries, is here accomplished, however, by the action of the epithelial cells, which, in a single layer, cover these membranes. These fluids may sometimes contain, in certain morbid conditions, excretory materials, such as urea, lactate of soda, sugar, and traces of bile pigment, all of which are manifest transudations.

The *serous* fluids, which must not be confounded with the serum of the blood, contains as much as 99 per cent. of water, a few salts, some albumen, and a substance slightly soluble in alcohol. They are thin and scanty in normal conditions, in the cavities of pleura, pericardium, peritoneum and arachnoid spaces, their use being merely to prevent friction. The aqueous humor of the eyeball may be regarded as a serous secretion, adapted by its locality to a very special purpose. When accumulated in abnormal quantity, from inflammation, serous fluids cause internal dropsies, and, in that case, generally contain traces of fibrin, which will slowly coagulate after removal from the body.

The *synovial fluid*, or *synovia*, is much more viscid than the serous fluid; it contains nearly 6.5 per cent. of albumen, together with fatty matter, salts resembling those of the blood, epithelial cells, corpuscles like the pale corpuscles of the blood, and, it is said by some, a substance closely resembling mucin. The use of this fluid, found alike in joints, in the so-called bursæ mucosæ, and in the sheaths of tendons, whether these move in grooves on the bones lined with cartilage, or in soft parts only, is chiefly mechanical, to prevent the effects of friction; but in the joints it may act nutritively on the cartilages.

EXCRETION.

The characters which distinguish excretion from secretion proper, have already been detailed (pp. 751–3). Its products, like those of secretion, are fluid or gaseous, at least in the human body, although semisolid or solid urine occurs in Birds and Reptiles. The term *excreta*, is also commonly applied to the solid materials ejected from the intestinal canal, as the residuum of the digestive process. These, however, are only partly excreted substances, such as unabsorbed biliary and other products more or less changed, substances thrown out by the intestinal glands, and undigested mucus and epithelium. The greater portion of the mass, however, consists of undigested food, such as elastic tissue, sarcolemma, the walls of vegetable cells, spiral ducts, and woody fibre.

The fluid excretions are those eliminated by the kidneys and the skin, the former excretion being the more complex. The exhalation of carbonic acid from the lungs, is an excretory process more immediately necessary to life than any other. The lungs may be regarded as excretory glands, and the carbonic acid expelled from them as a gaseous excretion; but the specialty of this process, its association with the absorption of oxygen, and its peculiar mechanism, render it necessary to consider the entire function separately, under the head of Respiration.

Renal Excretion.

The urine, excreted by the kidneys, is the most perfect example of a fluid excretion given off by the animal economy; its various constituents exist preformed in the blood; they are, moreover, highly oxidized nitrogenous products of the decomposition of the albuminoid tissues, and of the albuminoid constituents of the blood. They are destitute of organization, and incapable of it; neither can they be made, in animals, to undergo an ascensive chemical metamorphosis fitting them for nutrient purposes; they are of no further use in the organism, and, indeed, if retained, are highly injurious to it. Hence they are destined to be, once for all, separated, or *excreted* from it, and to be, as soon as possible, entirely discharged from the body. It facilitates this end that they are chiefly crystalloid bodies, and therefore easily dialyzable. It is provided, moreover, that a very large proportion of the blood should pass through the organs by which these substances are eliminated, for the quantity sent through them in twenty-four hours amounts to nearly 2000 lbs. (Brown-Séquard); so that all the blood in the body may pass through them 150 times in that period. Lastly, the excretion of urine is continuous or incessant.

The Kidneys.

The *kidneys* are two dense, firm, dark-red, solid, but fragile glandular organs, situated at the back part of the abdominal cavity, in the lumbar region, one at each side of the vertebral column, on a level with the last dorsal and the two or three upper lumbar vertebræ, and reaching from the eleventh rib to near the crest of the hip bone. The right kidney, owing to the proximity of the liver on that side, is about a rib's breadth lower than the left. The kidneys are placed behind the peritoneum, and are held in position by their bloodvessels, nerves, and the excretory ducts, called the *ureters;* they are likewise surrounded by an areolar tissue, usually loaded with fat, forming the so-called adipose coat, which, being a bad conductor of heat, serves to preserve the temperature of these organs. The shape of the kidney is well known and characteristic. Each is about 4 inches long, 2 wide, and 1 thick; the left one is rather longer and thinner than the right. In the male, each weighs from $4\frac{1}{2}$ to $5\frac{1}{2}$ ounces; in the female, about $\frac{1}{2}$ oz. less. The left kidney is generally about $\frac{1}{4}$ oz. heavier than the right. The weight of the two glands together, in proportion to that of the body, is about as 1 to 240. The specific gravity of the kidney substance is 1050. Its chemical composition is 76 per cent. of water, 15 of albuminoid substance, only 1 of fatty or resinous matter, which is chiefly cholesterin, together with certain extractives, including inosite, cystin, taurin, and xanthin.

If one kidney be atrophied or destroyed by disease, the other one usually enlarges. In certain cases, the kidneys are joined by a transverse portion of gland substance, the upper border of which is generally concave, the resulting mass forming the so-called *horseshoe* kidney. The two conjoined kidneys are sometimes found on one or other side of the lumbar region, or even in the pelvic cavity. A few instances are on record of the presence of three kidneys, the third gland, usually called a *movable* or *floating kidney*, being placed either on one side of the vertebral column, or in front of it, or else in the pelvis.

The upper end of each kidney is surmounted by the corresponding suprarenal body. Its internal concave border presents towards its middle a deep longitudinal fissure, called the *hilus*, which leads into a cavity within the organ, named the *sinus*. This gives exit and entrance to the bloodvessels, absorbents, and nerves, and also to the ureter; the renal or emulgent veins here lie in front, the ureter behind, and the renal arteries between them.

Fig. 109.

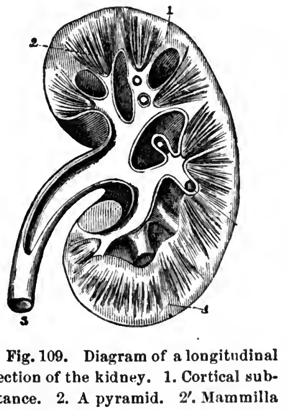


Fig. 109. Diagram of a longitudinal section of the kidney. 1. Cortical substance. 2. A pyramid. 2′. Mammilla or papilla of a pyramid, lying in its opened calyx. 3. A portion of ureter expanding above into the pelvis of the kidney, then dividing into the infundibula, and afterwards into the calyces.

The kidney is everywhere closely invested by a proper firm, smooth, *fibrous coat*, which may be readily torn off; it is, however, connected with the gland substance by numerous fine fibrous processes and vessels; it passes in at the hilus, lines the cavity of the sinus, and is even reflected on to the ureter and bloodvessels.

On making a longitudinal section of the kidney through the hilus, the solid gland substance is found to consist of an outer *cortical* portion, and of a deep-seated *medullary* portion. The *cortical* substance is continuous over the whole organ, and dips in between the different parts of the medullary portion, which is disposed in a series of conical masses. The cortical substance is about 2 lines in thickness, and forms about $\frac{3}{4}$ of the entire gland. It is of a reddish color, soft, granular, and friable, and contains a number of little round dark-red spots, which indicate the position of certain minute bodies, named the *Malpighian corpuscles of the kidney.* The conical masses of the medullary substance, from fifteen to twenty in number, form the so-called *pyramids* (Malpighi). Their bases, turned towards the surface of the kidneys, and also their sides, are encompassed by the cortical substance; but their apices are turned towards the sinus, in the interior of the organ, where they form little eminences, called the *papillæ* or *mammillæ.* The substance of the pyramids is firmer and darker than the cortical substance, and, as seen on a section, is striated from apex to base, the latter part being much darker than the former.

Outside the hilus, the ureter presents a funnel-shaped dilatation, or membranous cavity, called the *pelvis of the kidney*, which, as it passes into the sinus, divides into three tubes, named the *infundibula;* these again subdivide into from seven to thirteen smaller, also funnel-shaped, tubes, called the *calyces*, which surround, or embrace, the papillæ. One calyx often includes two, or even three, papillæ, so that they are usually fewer in number than the latter.

The cortical and medullary substances are both composed of minute closely packed *tubules* or *ducts*, the *tubuli uriniferi*, with bloodvessels, absorbents, and nerves, held together by a soft material of ill-defined structure. The latter is described as consisting of a very fine, scarcely recognizable, areolar tissue or stroma, more evident in the medullary portion, but forming, at the surface of the kidney, a thin layer beneath the fibrous coat; a parenchyma is also described by some. The different appearance of the cortical and medullary substances, depends on the different arrangement of their ducts and bloodvessels.

In the cortical portion the tubuli uriniferi are very numerous, much convoluted, and inosculate freely with each other; they are, on an average, about $\frac{1}{600}$th of an inch in diameter, and are known as the *tubes of Ferrein.* They generally commence by free closed extremities; sometimes, however, they anastomose together, forming loops; many are said to begin as minute purse-like dilatations, which form little partial *capsules* around the Malpighian corpuscles (Bowman); nearly all are somewhere connected with these capsules. In the pyramids, or medullary substance, the tubuli quickly unite together many times, dichotomously or by twos, and becoming larger and straight, constitute the so-called *ducts of Bellini;* these form tapering bundles, directed to the papillæ, or apices, of the pyramids, on which they open by minute round orifices. It has been estimated that there are as many as two millions of tubuli in each kidney; that the number of orifices in a square line of a papilla, are 100; and that there are from 300 to 500 on the surface of a single papilla. (Krause.) The straight tubuli are widest near their orifices, measuring from $\frac{1}{250}$th to $\frac{1}{400}$th of an inch; they cause the striated appearance of the pyramids. The uriniferous tubules are composed of a transparent basement membrane, lined with a thick polygonal, or spheroidal, glandular epithelium, which occupies about two-thirds of the diameter of the membranous tube. The epithelial cells have very delicate walls, a roundish nucleus, fine granular albuminoid contents, and occasional fat, pigment, and other particles. This epithelial layer is continuous with that covering the free surface of the papillæ. In the cold-blooded Vertebrata, it is, in parts, provided with cilia.

The *Malpighian corpuscles* of the cortical substance are placed either at the free closed extremities of the convoluted tubuli, or in the course of the loops which these occasionally form. These little bodies, the *glomeruli* of Ruysch (1660), are spheroidal, and measure about $\frac{1}{120}$th of an inch in diameter. Each is composed of a rounded, close coil of minute vessels, which projects, like a little ball, into one of the capsules of the tubuli. It appears that a minute branch of the renal artery, named an *afferent* vessel, reaches each Malpighian body, and, dividing into superficial coiled branches, forms a globular network; from the centre of this an *efferent* vessel arises, and, leaving the corpuscle, forms, with the efferent vessels from neighboring corpuscles, a dense vascular plexus, which surrounds the contiguous tubuli. According as the capsule of the Malpighian corpuscle is formed at the commencement, or the side of a tubule, it is said to be *lateral* or *terminal*. At the mouth of the capsule the spheroidal epithelium of the tubule loses its character; for within the capsule the epithelium is squamous and remarkably thin. It is said by some to be continued over the surface of the Malpighian corpuscle which projects into the capsule. (Gerlach, Isaacs.) But according to Bowman the corpuscle lies naked in the capsule, without any such covering, the afferent and efferent vessels being supposed to perforate the capsule. These vessels enter and pass out at nearly the same part of the corpuscle, which is there attached to its capsule. According to some observers the efferent vessel is always *narrower* than the afferent one, and hence has arisen the idea that the blood is checked, or held back, in the coiled vessels of the corpuscle. The central vessels of the corpuscles are, by some physiologists, regarded as capillaries, and the efferent vessel as a vein, which then breaks up to form the fine plexus around the adjoining tubule—an arrangement supposed to represent, on a very minute scale, a renal *portal* system. But all the coiled vessels, and even the efferent vessel of the Malpighian corpuscles are, by others, considered to be arterial, the whole forming a microscopic *rete mirabile*, which ultimately, by the efferent vessel, ends in a true capillary network around the tubules.

The *renal* or *emulgent arteries*, right and left, spring from the sides of the aorta; they are short, and very large for the size of the kidneys, being out of proportion to the mere nutritive necessities of these organs. They soon divide into four or five branches, which pass between the pyramids, and are partly distributed in the form of nutrient vessels, to the cortical and medullary substances, and to the common coat of the kidney; but they chiefly terminate in the Malpighian corpuscles, or in the fine vascular network which surrounds the tubuli. The *veins* accompany the arteries, and end, for each kidney, in a single large renal or emulgent vein, which joins the ascending vena cava. The *lymphatics* are numerous, and consist of a superficial and deep set. The renal *nerves* are small but numerous, and may be traced even on to the afferent arteries of the Malpighian corpuscles; but their mode of termination is unknown. They are derived from the sympathetic nerves found on the renal artery, and from the lesser splanchnic nerve.

The ureter, its pelvis and calyces, are composed of an external fibro-elastic coat, continuous with the proper capsule of the kidney; of a muscular layer, which consists of external longitudinal and internal circular fibres; and of a mucous coat, continued on to the papillæ, and lined with a spheroidal epithelium. The ureters, in animals, contract slowly on the application of galvanism or other stimuli; sometimes they act rhythmically. Their lower ends enter at each side, the fundus or base of the urinary bladder penetrating its coats obliquely, and opening into it by a narrow elongated orifice, so guarded by muscular bundles that the reflux of urine into them is prevented.

Action of the Kidneys.

The purpose of the enormous number of uriniferous tubes is, as in glands generally, to increase the extent of secreting or excreting surface, within a given space. It has been calculated that the total amount of surface in the coiled tubes in each kidney exceeds forty-four square feet; and to this must be added the excreting surface of the straight tubuli as well. (Vierordt.) The Malpighian bodies are quite peculiar to the kidneys, these little vascular coils, projecting into a duct, having no resemblance to the solid sacs which bear the same name in the ductless gland, the spleen. So special a structure has doubtless some special office. Since these bodies have been shown to project into the tubuli, at or near their commencement, it has been conjectured that they separate from the blood the greater part of the water of the urine, and that then the inspissated blood which passes from them by the efferent vessels enters the vascular plexus around the tubuli, and yields to the spheroidal epithelium the proper solid constituents of the urine, which are thence excreted in the tubules themselves, and are washed away out of those canals by the watery exudation descending from the Malpighian corpuscles. The naked condition of the glomerulus, and the squamous character of its epithelium, are fitted for a simple process of transudation; whilst the spheroidal epithelium of the tubuli is adapted to a true excreting office, though the walls of the tubuli must likewise excrete a little water. It is impossible to deny, moreover, that the glomeruli have also a true excreting office. It is now believed to be certain that all the blood of the renal arteries goes through these Malpighian corpuscles before it reaches the tubules, and if it then becomes inspissated, the blood which circulates around the tubules may be compared to the portal blood of the liver, being, as it were, venous blood highly charged with materials destined to be separated from it. In support of the view that the Malpighian corpuscles separate the water, it has been urged that in Birds and Reptiles, in which the urine is partly, or almost entirely, solid—though in the Amphibia and Fishes, lower in the scale, it is again fluid—these bodies, though numerous, are remarkably small. Moreover, the analogy of the minute vascular arrangements within the kidney, with a portal system, is thought to be favored by the fact that, in Reptiles, a branch from the hepatic portal vein is distributed to the kidney.

That some, at least, of the peculiar constituents of the urine, of which urea, uric acid, creatin, and creatinin are the chief, exist preformed in the blood, is certain; for the two latter are found in it in considerable quantity, urea in smaller quantity, and uric acid perhaps only as an exceptional ingredient. It has been suggested that the urea and the other crystalloids present in the inspissated blood may pass, by swift dialysis, into the aqueous contents of the tubuli; but though these substances, and urea especially, are highly dialyzable, yet such a physical explanation of their separation from the blood, would not account for their special appearance in the renal excretion, rather than in any other, or, for the quantity eliminated from the system in a given time, considering how minute is the normal proportion of urea, and how much less that of uric acid, in the blood. It is, indeed, impossible to deny that the spheroidal epithelial cells of the tubes, have a special affinity for the proper urinary constituents; or, and this may be of more moment in explaining their appearance in the urine, that some of these substances are formed by the special metamorphoses of other materials within these cells. In the former case, the cells would merely select the urinary constituents from the blood, and transmit them into the tubuli; in the latter, they would, in addition, be the seat of special chemical decompositions. In the first case, for example, they might be supposed to separate pre-existing urea from the blood, but, in the latter, to metamorphose creatin or creatinin into urea. Indeed, after extirpation of the kidneys—an operation which animals will outlive a few days—the blood is not found to contain much urea, but to be rich in nitrogenous extractive matters, which include creatin and creatinin. Moreover, if the ureters be tied, so that the escape of the urine from the excreting structure of the kidneys is at first hindered, and at last prevented, urea is found in great abundance in the blood, as if its formation had gone on in the spheroidal epithelial cells, and it had been duly excreted, but then reabsorbed, or else had been absorbed from those cells directly into the blood.

It is further supposed that the smaller relative diameter of the efferent vessels of the glomeruli, and the unusual blood pressure in the renal arteries, may have an influence in the excretory work of the renal apparatus. By some, it is thought, that a selective or metamorphic power of the cells, is indicated by the fact, that uric acid salts are actually seen, in the cells lining the straight tubuli, in the kidneys of Birds. Whilst the products of the decomposition of the tissues are passing from the inspissated blood of the vascular plexus upon the tubules, into the epithelial cells, some of the thin watery fluid within the tubes is reabsorbed by those vessels, and thus the renal blood partly regains its fluidity, whilst the urine becomes more concentrated.

Under excessive pressure in the arterial blood-columns of the kidneys, as, *e. g.*, when the aorta is tied below the points of origin of the renal arteries, albumen appears in the urine. The same event happens from obstruction of the renal ducts or vessels, or from the pressure of tumors upon them. This is not a dialytic process, albumen being a colloid substance, and difficult to dialyze; but it is probably an example of simple porous diffusion or filtration. In acute inflammatory conditions, fibrinous exudations from the blood form in the tubuli, and appear in the urine as minute coagula or *casts*.

The urine excreted into the tubuli, urged on by the *vis a tergo* of a constant process of excretion, escapes from their orifices into the calyces. From these, it descends along the infundibula, the pelves of the kidneys, and the ureters, into the bladder, partly by gravity, and probably partly propelled by the rhythmic peristaltic actions of the muscular coat of those canals. Accumulated in the bladder, it becomes further concentrated by absorption of water, and is mixed with mucus from the ducts and from that viscus.

The *constancy* and the great *rapidity* of the excretion of urine, have been observed in cases of malformation, known as inversion of the bladder, in which the lower part of the abdomen and the anterior portion of the urinary bladder are defective, so that the fundus of this organ, into which the ureters open, is exposed. Under ordinary circumstances, the urine is seen to flow in drops, from the mouths of the ureters; but, after drinking freely, it runs in little streams.

The urinary excretion is affected, both in quantity and quality, by the nervous system. Thus, it is increased in quantity, and lowered in quality, by hysteria, fear, and other mental emotions, this effect being probably due to dilatation of the renal arteries. Injury of the spinal cord affects the urine, chiefly causing a great development of carbonate of ammonia and the precipitation of phosphates, owing, it appears, to congestion and inflammation of the bladder, with an increased secretion of mucus from it. Complete removal of the brain and spinal cord, in animals, does not much affect this excretion.

The walls of the bladder chiefly consist of layers of unstriped muscular fibres, collected into bundles, arrranged like figures of 8, on the front, back, and sides of the organ. Some of these, surrounding the neck, act like a *sphincter;* the others form *detrusor*, or expellent muscles. The act of emptying the bladder requires the simultaneous relaxation of the one, and the contraction of the other set. These are usually reflex acts, excited directly by the accumulated fluid, or by some irritation of the nervous system. The act of expulsion is aided by the contraction of the abdominal walls.

The Urine.

The daily quantity of fluid excreted by the kidneys of an adult healthy man, varies from 30 oz. to 80 oz.; but, on an average, it has been estimated at about 50 oz. This quantity varies according to the amount of fluid taken in the food and as beverage, the activity of exhalation by the skin and lungs, and the amount excreted by the intestinal canal. More fluid is excreted by the kidneys in winter than in summer, the skin being less active in the former, and more so in the latter season. The quantity is said to be increased under higher barometric pressure. The specific gravity of the urine differs much, not merely according to the different proportions, but also according to the different *nature* of its solid constituents; in health, it may range from 1015 to 1030; usually, however, it deviates only slightly from 1020. The urine excreted after drinking much water, and taking little or no food, which is named *urina potûs*, is of course of low specific gravity; that after eating a full meal, is of high specific gravity, and is called *urina cibi vel chyli;* whilst after complete abstinence from both food and drink, as in the morning, it is most completely saturated with solid constituents, and is therefore at its highest specific gravity; it is then called *urina sanguinis*. The amount of solid constituents is irrespective of that of the fluid, and depends on the activity of the metamorphosis of the tissues, and of the superabundant food. Its usual bright amber color varies, according to its density, from that of a colorless fluid to a deep yellowish-brown. In disease, the color and specific gravity present important variations; thus, in Bright's disease of the kidneys, the specific gravity may be as low as 1003, being little higher than that of water; its proper constituents are then deficient, whilst albumen, derived from the plasma of the blood, is present; on the other hand, in diabetes mellitus, in which the urine contains sugar, the specific gravity may be as high as 1050. The peculiar odor of the urine is strongly developed by a heat sufficient to produce evaporation. The natural reaction of this fluid is acid, but after digestion, and especially after a vegetable diet, it may become alkaline; in herbivorous animals, this is its normal character. The cause of its acidity will be discussed after its chemical composition has been described. From a particular kind of decomposition, known as the acid fermentation, its acidity may be increased, after it has been excreted; on the other hand, by a decomposition of the urea, in which carbonate of ammonia is generated, it may acquire a strong alkaline reaction a few hours after its excretion, or even, in certain diseases, whilst it is yet retained in the bladder. In such a condition, an abnormal deposit of phosphates takes place.

Normal urine consists of water, holding a very variable quantity—viz., from 2 to 7 per cent.—of solid substances, of which urea is the chief; besides this, there are uric and hippuric acids, free carbonic acid, often lactic acid, occasionally oxalic acid, extractive nitrogenous matters, partly crystallizable, such as creatin and creatinin, xanthin, phenylic, carbolic, benzoic, and other acids, uncrystallizable extractives of uncertain composition, small quantities of special pigments, traces of fatty matter, numerous salts, such as sulphates, phosphates and chlorides of potash, soda, lime, and magnesia, with silica, mucus, and epithelium. The relative proportions of its various solid constituents in 100 parts, and the daily average quantity of each, excreted from every 1 lb. weight of the body, in a man weighing 145 lbs. avoirdupois, are shown in the annexed Tables.

Daily quantity for 1 *lb. weight of body substance, in a Man of* 145 *lbs. weight* (Parkes).

Water,	2.9 drachms.
Urea,	3.53 grains.
Uric acid,	.059 "
Hippuric acid,	.237 "
Creatin,	.032 "
Creatinin,	.048 "
Coloring matter, and other extractives,	1.062 "
Sulphuric acid,	.214 "
Phosphoric acid,	.336 "
Chlorine,	.875 "

Composition of 100 *parts of the Solid Constituents* (Lehmann).

Urea,	49.68
Uric acid,	1.61
Extractives: Creatin, Creatinin, Hippuric acid, Salts of Ammonia, Chloride of Sodium,	28.95
Alkaline sulphates,	11.58
Alkaline phosphates,	5.96
Phosphates of lime and magnesia,	1.97

The *water* of the daily urine equals about one-half of that taken into the stomach; supposing the total quantity of the excretion to be from 30 to 50 oz., the water would be from 28 oz. to 47 oz. The *solid constituents* amount to from 2 oz. to 3 oz. in the twenty-four hours.

The *urea* is by far the most important and characteristic substance, amounting to upwards of an ounce, or half the solid constituents in 24 hours, or, according to some estimates, to as much as 500 grains. Its atomic composition, CH_4N_2O corresponds with that of carbamide, COH_4N_2, and also with that of 1 atom of hydric cyanate of ammonia, viz., $CNOH+NH_3$. It is readily transmutable, by the absorption of the elements of two atoms of water, into carbonate of ammonia, one atom of which contains $CO_3+2(NH_4)$. Urea is thus obtained: Evaporate cautiously a considerable quantity of urine to the consistence of syrup; to this, add slowly its bulk of nitric acid, when certain crystals are thrown down, which are nitrate of urea; dry these upon a filter, decolorize them by dissolving them in water, and boiling with animal charcoal, and recrystallize; once more dissolve the crystals and now separate the nitric acid, by means of carbonate of baryta. On evaporating the solution, a pasty substance is left, from which alcohol dissolves out the urea, and the filtered solution yields, on evaporation, pure crystals of this substance. These crystals are long, colorless, four-sided prisms, extremely soluble in hot, and even in cold, water; hence urea never enters into the composition of urinary sediments or calculi. It dialyzes most actively. It is neutral in its reaction to test paper; but it acts as a base, combining with acids to form definite salts. As hydric cyanate of ammonia is identical in composition, crystalline form, and chemical properties, with urea, and as the former substance can be made in the laboratory, it affords an example of the imitation of an organic compound, by artificial means. (Wöhler.) Urea contains 46.7 per cent. of nitrogen, together with 20 per cent.

of carbon. One ounce, taken as the ordinary daily excretion, contains about 220 grains of nitrogen.

The *sources* of the urea are evidently nitrogenous organic compounds, which have undergone decomposition by partial oxidation. It constitutes the highest product of oxidation of the albuminoid and gelatinoid substances in the body. It is derived, partly from the tissues, but partly from the food, merely assimilated into blood; not, as was at one time supposed, from the tissues only. This is proved by many facts. Thus, the urea is always increased after meals, especially about three or four hours after the food is taken. In animals fed on too little nitrogenous food to counterbalance the waste of the albuminoid tissues, more urea is given off than the nitrogen in the food would form; when the waste is just compensated for, then the urea is equal to the nitrogen in the food; lastly, when an excess of nitrogenous food is given, the weight of the animal increases, and, after a time, an excess of urea is eliminated. Urea is still excreted, even in starving animals, though in smaller quantity than usual; it is increased by feeding them on a vegetable diet containing nitrogen, especially on bread and beans; its quantity is still greater, on a mixed vegetable and animal diet, but it is greatest of all, on an exclusively animal diet. In a dog weighing 30 kilogrammes, the daily excretion of urea, with a pure animal diet, varied from 150 to 180 grammes—that is, it equalled $\frac{1}{200}$th or $\frac{1}{160}$th of the weight of the body. In Man, with an exclusively animal diet, the daily quantity excreted was found by Lehmann to be about 820 grains, with a mixed diet 500 grains, with a vegetable diet 347 grains, and with a completely non-nitrogenous diet 237 grains. The researches of Dr. E. Smith confirm these results, and further show that an animal diet increases the excretion of carbonic acid from the lungs. In other experiments, the quantity excreted daily, on a superabundant animal diet, was found to be nearly 3 oz.; on a moderately animal diet continued for ten days, from $1\frac{3}{4}$ to 2 oz.; and after a diet of sugar, prolonged for four days, the daily quantity of urea was rather less than $\frac{1}{2}$ oz. Not only, then, is urea formed largely from the food, but chiefly so, the quantity derived from the tissues, as above shown, when a non-nitrogenous saccharine diet was taken, being less than half the ordinary daily amount. Sometimes even more is eliminated during a total abstinence from food, as if, in the latter condition, an animal maintained its temperature by waste of its nitrogenous tissues.

In the female, from her smaller frame, her less active nutrient metamorphoses, and the smaller quantity of food consumed, the daily quantity excreted is about $\frac{3}{4}$ of an oz. Proportionally to the weight of the body, it is less abundantly formed in women; but children up to seven years old excrete about twice as much urea, proportionally, as adults, and infants more than children; in old age, the relative amount is diminished. The effect of age depends upon the diminished activity of the nutritive functions, and the smaller quantity of the food. Exercise was formerly believed to increase the quantity of urea, and rest to have the opposite effect; but recent observations show that the immediate effect of exercise is to diminish the excretion of urea, though towards the end of labor, and especially in the period of rest afterwards, it is greatly increased. Gelatin, which seems never to be directly assimilated by the tissues, but rather to save them from oxidation, is readily, perhaps directly, converted into urea. Water, especially if taken with food, causes an increase in the ureal excretion, and also in that of the saline constituents of the urine. Diminished temperature and increased barometric pressure, are said to increase the quantity of urea. In most cases, the urea is not eliminated until some hours after its actual formation in the system, or until the determining cause of its increase has taken effect. The quantity excreted is greater during the day than in the night. Common salt, phosphoric acid, theobromine, urea itself, uric acid, and cantharides, are found to increase the amount of urea excreted, whilst tea, but especially coffee, alcohol, turpentine, and digitalis, diminish it. It is remarkable that such large quantities of nitrogen and carbon are eliminated from the system in the form of urea—a comparatively inactive chemical substance; whereas carbonate of ammonia, a compound readily produced from the elements of urea, and an extremely irritating and noxious substance, is not formed in quantity, in the animal economy. In certain diseases of the kidneys, the urea is not excreted, but, the blood becoming vitiated, uræmic poisoning occurs, characterized by symptoms, such as convulsions and coma, referrible to the nervous centres, and often fatal. It was formerly supposed that the urea itself is the toxic agent, but possibly it is the carbonate of ammonia derived from the decomposition of the urea. In these cases, ammonia is found in the breath, and, after death, in the blood; the injection of that substance into the veins of an animal also causes similar symptoms. A dilute solution of urea, to which a small quantity of mucus or other animal substance is added, readily ferments, and, evolving a pungent odor, forms carbonate of ammonia; this kind of fermentation may take place very rapidly, even within the bladder. The amount of urea increases in all those diseases which are accompanied by an increase of tissue change, such as active inflammation of the lungs, or of the membranes of the brain, and in fevers generally, even though less food and exercise are taken than in health. In fever, the quantity has been found to be double the ordinary amount, viz., 1065 grains daily; in pyæmia, it has reached 1235 grains. (Vogel and Warnecke.) During recovery, the quantity excreted falls for a time, although more food and exercise are taken.

Uric acid is found not only in the urine, but also in the blood, and in most organs of the body. It contains 33.3 per cent. of nitrogen, and has the following composition: $C_5H_4N_4O_3$; it is therefore regarded as resulting from a less complete oxidation of the nitrogenous compounds of the food and of the body than that which produces urea. The formation of urea in the system is supposed, by some, to be normally preceded by that of uric acid. The former may be easily produced from the latter, by processes in which oxidation forms a part; when an alkaline urate is digested with portions of liver, at a certain temperature, urea is formed at the expense of the uric acid. Animals to which uric acid is administered with the food, excrete an unusually large quantity of urea. Some of the products of the metamorphosis of the muscular tissue, such as creatin, xanthin, and sarcin, have affinities with uric acid. Lastly, in a state of rest, the quantity of uric acid excreted increases, whilst the urea ultimately diminishes, the reverse being the case from exercise.

The quantity of uric acid excreted daily, has been estimated at from $8\frac{1}{2}$ to 15 grains; but this, like the quantity of urea, varies very much, most markedly according to the amount of nitrogenous food which is taken, and less so according to the age and sex. Its quantity is lessened by exercise. With animal diet, its quantity is said to be 4.5 grains, and with vegetable diet, only about 1.5 grain daily. (Haughton.) In the urine, it is either combined with soda, forming the urate of soda, which is held in solution, or else it is dissolved by the alkaline phosphate of soda. Being less soluble than its salts, uric acid is quickly precipitated by acids, and moreover, being itself less soluble in cold than in warm water, it is commonly precipitated from normal urine after cooling. This may be partly from the diminished solvent power of the cooler fluid, and partly from the occurrence of the lactic acid fermentation. Uric acid is then precipitated and deposited, either in an amorphous powder, or in fine crystals of peculiar forms, often tinged with coloring matter. The crystals are sometimes little flattened rhomboids, sometimes they resemble a coffin or a barrel, and sometimes they are almost spherical. It forms the most common urinary sediment, and the most frequent kind of renal or vesical calculus or stone in the kidney or bladder. Hence it is also named *lithic* acid (λιθος, a stone). Urate of soda constitutes the solid urinary excretion of Serpents, and is also present, in large quantity, in the white pasty portions of the dejecta of the flesh and fish-eating Birds, such as the hawks and owls, the penguins and other sea-birds. Hence it exists in large quantity in guano. It may be obtained pure from human calculi, or from the solid excretion of the serpent, by dissolving the urate in those substances in a hot solution of caustic potash, and reprecipitating it from the filtered fluid, by means of another acid. The precipitate is a white powder, composed of colorless rhomboidal scales; it is almost insoluble in cold water, and only slightly so in hot, and is absolutely insoluble in alcohol and ether; it is soluble in alkaline solutions, and very readily in solutions of lithia. From all these solutions, it is immediately reprecipitated, even by feeble acids. Heated nearly to dryness with nitric acid, uric acid turns red, and, on the addition of ammonia, a beautiful purple substance, named *murexid*, is formed, a reaction which constitutes a test for uric acid. The fact that uric acid is a less perfectly oxidized compound than urea, explains, perhaps, its formation in excess under certain conditions, as, *e. g.*, when the quantity of tissue metamorphosed, or the quantity of food taken, is greater than the supply of oxygen can convert into urea, as, *e. g.*, in acute inflammations, rheumatism, and gout, in all which diseases, large quantities of uric acid deposits, or of urates, are thrown down from the urine, which is loaded at critical periods, after the climax of the attack. At the onset of the gout, the uric acid sometimes nearly, or entirely, disappears from the urine; it may then be detected in the blood. The gouty concretions, known as chalk-stones, are composed of urate of soda, with traces of urate of lime. When, in acute inflammatory disease, the uric acid is increased, the urea is simultaneously diminished. In diseases of debility, this acid is usually diminished in quantity; it may also be reduced by a spare diet, the avoidance of acids, the use of large quantities of water, open-air exercise, so as to insure the perfect oxygenation of the blood, and by all measures tending to increase the action of the skin, such as exertion, friction, baths, especially hot-air and water baths, and warm climates. The use of tobacco augments its excretion, whilst quinine and alcohol lessen it. Alkalies assist in its excretion.

Hippuric acid (ἵππος, a horse), first detected in the urine of the horse, is also constantly present in human urine, sometimes amounting to as much as 15 grains in twenty-four hours; it has often been overlooked. (Liebig.) It crystallizes in four-sided prisms, and has the atomic composition, $C_9H_9NO_3$, so that it is neither so nitrogenous nor so completely an oxidized body as urea or uric acid, but contains a larger proportion of carbon than either substance. Benzoic acid and other benzoyl compounds, also oil of bitter almonds, and succinic and other allied acids, when taken internally, cause an excess of hippuric acid in the urine (Ure). To explain this, it has been suggested that benzoic acid, $C_7H_6O_2$, combined with the bile product, glycocoll, $C_2H_5NO_2$, is equal to one atom of hippuric acid, and one atom of water. The source of the hippuric acid ordinarily present is not yet known. Its quantity is influenced by the character of the diet, and by the amount of exercise; it is increased by a purely vegetable diet, is lessened by a mixed diet, and is diminished still more remarkably in those who are living on animal food only. According to some, it is absent in persons who abstain from spices; also in infants at the breast, and in Herbivorous animals deprived of food. In the last two cases, uric acid alone is produced, in the one case, from the milk, and in the other, from the tissues of the animal itself. (Ranke.) Hippuric acid is not only found in large quantities in the horse, but also in other Herbivorous animals; and most of these consume grasses, in many species of which certain aromatic principles exist. In the Carnivora, it exists in minute quantities. Although, most probably, hippuric acid is commonly derived from certain aromatic substances, yet it has been shown that its formation from albuminoid bodies is quite possible. (Städeler.)

Very minute quantities of benzoic acid, and xanthin or xanthic oxide, also exist in the urine, with traces of certain volatile acids, phenylic, carbolic, and taurilic, on which the odor of this fluid may depend.

The *creatin* and *creatinin* found in the urine, are both crystallizable nitrogenous bodies. The former exists in small quantities, the latter amounts to about 15 grains a day. Creatinin $C_4H_7N_3O+2(HO)$, differs from creatin $C_4H_9N_3O_2$ by one atom of water. They are obtained by precipitation with salts of zinc, and by the subsequent decomposition of the zinc compounds. Creatin is a neutral substance, incapable of combining either with acids or alkalies; but creatinin is a powerful base, having a strong alkaline reaction, and forming crystallizable salts with acids. Creatin exists in large quantities in the juice of muscle, from which it was first prepared by Liebig. Creatinin is present only in small quantity in the juice of flesh, but is readily formed by the action of strong acids upon creatin. Creatin appears to be, with succinic acid, a product of the decomposition of syntonin, whilst creatinin results from still further decomposition; from its basic nature, it approaches in character to urea, into which substance, and sarcosin, it is decomposed by the action of baryta at the boiling-point. Albumen may be broken up artificially, by the action of powerful acids or alkalies, into glycocoll, tyrosin, and leucin, nitrogenous bodies intermediate between it and urea. By the action of caustic alkalies on creatin, urea is formed, whether through the previous formation of creatinin is not certain. Albumen, creatin, creatinin, and urea, form, therefore, a descending series of nitrogenous bodies. Both creatin and creatinin are more abundant in exercised muscles, and, therefore, would seem to be products of muscular action; both substances are present, in small proportions, in healthy blood, from which they are excreted, also in small quantity, by the kidneys. They are supposed to be transformed chiefly into urea, probably through the agency of the epithelial cells of the uriniferous tubes, and, thus changed, finally enter the urine. Creatin and creatinin, therefore, are compounds probably preformed in the body, *i. e.*, in the muscles, thence entering the blood by venous absorption; they are excreted from it, in minute quantity, in their proper form, but chiefly after conversion into urea. They are the principal immediate source of the last-named substance, which is even associated with them in the juice of the flesh of certain Cartilaginous Fishes. (Frerichs and Städeler.)

The *coloring* substance of the urine, *urinary pigment* or uro-hæmatin, contains iron, and is separable into red, blue, and yellow coloring matters, named uro-rhodin, uro-glaucin, and uro-xanthin. Their nature is not well understood; they exist but in small quantity, and are very prone to decomposition. According to some, these pigments are allied to indigo, and its derivatives, indigo-red, indigo-blue, and indican. The blue pigment, or uro-cyanide, is named the indigo of urine.

The non-crystallizable extractive matters of the urine exist in large quantities, and require further investigation; they are nitrogenous bodies, some even containing sulphur and phosphorus, probably derived from the albuminoid tissues; they are liable to decompose, and are abundant in certain diseased conditions.

Traces of mucus and epithelium, either of the spheroidal glandular kind from the tubuli, or of the squamous kind from the interior of the bladder, also occur, as cloudy deposits, in this excretion.

There are also several non-nitrogenous, hydro-carbonaceous, or carbonaceous substances in urine. Thus, *lactic acid*, $C_3H_6O_3$, occurs occasionally, as, *e. g.*, when that acid, or some of its salts, are present in large quantity in the blood, owing to feeble conditions of the respiratory process, or to defective oxidating processes in the blood. By Lehmann, lactic acid is said to be constantly present, and to be the cause of the acidity of the urine; but, by others, this is supposed to depend upon free phosphoric acid, or, an acid phosphate of soda, or perhaps upon this acid, together with a minute quantity of dissolved uric acid; for it is difficult to suppose the existence of free lactic acid, so long as any alkaline urates are present, and these latter salts may always be obtained by the quick evaporation, *in vacuo*, of perfectly fresh urine. The acidity of the urine gradually diminishes for from three to five hours after a meal, and sometimes the excretion becomes actually alkaline. This effect occurs simultaneously with the development of the large quantity of acid in the gastric juice poured out for the digestion of the food; whilst the return of the urine to its acid condition during fasting, corresponds with the cessation of the formation of acid in the stomach. This temporary diminution in the acidity of the urine, or its positive alkalinity, is most marked when animal food is taken, which requires more acid to digest it; with vegetable food it is less so; with mixed diet, the effects are intermediate. (Roberts.) The alkalinity of the urine after a vegetable diet, and of that of the Herbivora generally, is not opposed to these observations, and has another explanation. In such diet, large quantities of neutral alkaline salts of the vegetable acids are met with, which are converted in the alimentary canal, or in the blood, into carbonates; the quantity of albuminoid food or tissue metamorphosed is so small as not to yield enough sulphuric and phosphoric acid to neutralize this alkali. The urine is also often alkaline in gastric disorder. In the Carnivora, ammonia acts the part of a base to the acids of the urine, instead of the fixed alkalies.

Oxalic acid, $C_2O_3+H_2O$, also occurs in the urine, especially after eating fruit, which contains organic acids, also after drinking fluids containing free carbonic acid, and, lastly, when the respiratory process is seriously disturbed. Any condition which tends to overload the blood with carbonic acid favors the appearance of oxalic acid in the urine; in children it is a frequent constituent, and, in combination with lime, forms the comparatively common *mulberry calculus*. Lastly, *carbonic* acid itself is found in a state of solution, in the quite recently discharged urine of both man and animals. Besides this, the urine contains nitrogen, with traces of oxygen, and, but only as a product of decomposition, sulphuretted hydrogen.

Minute traces of certain *fats*, such as olein and stearin, occur in urine. In certain cases, a fatty substance, probably a mixture of ordinary fats, named *keistin*, appears as a scum upon it; and, in altered conditions of the kidneys, large quantities of oily matter rise up to the surface.

The *salts* found in the urine average about 1.8 per cent. of that fluid, though they vary extremely, according to the character of the food and the amount of fluid ingesta; the latter increase their quantity. Of 100 parts of these salts, the sulphates form 45 parts, the phosphates 24, and the chlorides 23, the residue consisting of salts of the organic acids. The chief base is soda, next in order potash, then ammonia, magnesia, lime, and lastly, in minute quantities, iron and silica. Whilst most of these salts are derived directly from the materials of the food, others undoubtedly proceed from the metamorphoses of the tissues; but even these are, of course, ultimately derived from the food. The sulphates and phosphates of the alkalies, originate in the oxidation of the sulphur and phosphorus belonging to the albuminoid substances found especially in the muscular and nervous tissues; the quantity of these salts is increased by exercise, which conduces to changes in those tissues. The earthy phosphates must also be ultimately derived from the food, either directly, or through tissue changes; their quantity appears to increase, on the administration of chloride of sodium. The chloride of sodium itself varies in quantity, according to the amount consumed with the food; one office of the kidneys is to regulate the quantity of that salt retained in the blood. The ammonia of healthy urine occurs chiefly in the triple phosphate of ammonia and magnesia; it is an ultimate product of the decomposition of albuminoid substances, the creatin, creatinin and urea being probably intermediate stages.

Under certain circumstances, amorphous or crystallized deposits, or *sediments*, are formed in the urine; and sometimes, even solid concretions, named *urinary calculi* or *stones*, occur in it even within the body.

The most common sediment is of a *yellowish* or *reddish* hue, and consists of mixed *urates* and *uric acid*, with some of the coloring principles; these being less soluble in cold than in hot fluids, may be precipitated from urine, clear at the time of its discharge from the body. When turbidity exists at the moment of discharge, or subsequently, though the urine be maintained at the temperature of the interior of the body, the condition must be regarded as one deviating from health. But a uric acid sediment may be caused by an acid fermentation of the urine, often associated with the growth of penicillium. The acid then formed, usually lactic acid, decomposes the urates in solution, and uniting with their base, whether soda or ammonia, precipitates the less soluble uric acid. The colored extractive matters may, through changes produced in them by atmospheric action, increase the solvent power of the fluid for the urates, and so prevent their precipitation in the process of cooling. The quantity of uric acid sediment, therefore, does not necessarily correspond with that in the urine itself, for sometimes it may be precipitated, though existing in small proportion, and sometimes be suspended, though present in larger quantity. If the uric acid compounds be in excess, the temperature lowered, and a free acid be formed, a deposit is sure to take place. In hot climates, the cutaneous excretion is very active, a quantity of acid is thus removed from the system, and deposits of lithic acid are accordingly rare. *Phosphatic* sediments are also occasionally met with, owing to peculiar decompositions or fermentations, affecting the urea, which is then converted into carbonate of ammonia; by this, the earthy phosphates are precipitated, as ammoniacal magnesian phosphate, or as phosphate of lime. This alkaline fermentation occurs sooner or later, at certain temperatures; but in those diseases in which the urine is too long retained in that viscus, and also in inflammation of the urinary mucous membrane, it sometimes happens in the bladder itself. This form of alkalinity is to be distinguished from that which depends on the presence of potash or soda; in the latter case, the blue color given to litmus paper is permanent; whilst with ammoniacal urine, it is fugitive, owing to the volatility of ammonia. The alkaline fermentation is probably induced by the pus, or by the excess of mucus. The acid fermentation is also believed to be excited by the mucus of the bladder. The abundant sediments formed in the critical stages of fevers and gout, are of the uric acid type. The fine iridescent film, frequently seen on the surface of the urine, in dyspeptic and nervous diseases, consists of crystals of the triple phosphate of ammonia and magnesia. Prolonged mental effort is said to cause an increase in the amount of phosphates; but this is not established by observation, although this condition does occur in diseases of the nervous centres. The known existence of phosphorus in the fatty matter of the brain, has doubtless suggested this idea. Other morbid sediments consist of pus and blood.

The concrete deposits named *calculi*, commence by the collection of some crystallizable substance, around accidental fibrinous or other masses which may be minute, and ultimately almost or entirely disappear. Upon such a centre of formation or *nucleus*, successive layers of crystallized substance are deposited in laminæ or crusts, cemented together by traces of mucus. The first layers deposited, often differ from those which follow, and sometimes the layers alternate, constituting a *composite* calculus. The simplest calculi are those consisting of a mixture of uric acid with urates, forming the *uric* or *lithic acid* group; they are generally oval, somewhat flattened, smooth, or slightly rough, yellowish, and hard. The *oxalate of lime* or mulberry calculi are, as their name implies, roughly tuberculated, and brownish or black in color; they are very hard. They contain some coloring substance derived from the blood. The *phosphatic* calculi are either smooth on the surface, opaque-white, or white and semi-transparent, or else finely crystalline, light and soft, so as, indeed, to be easily worn by attrition, when two or more coexist in the bladder; they offer but little resistance to crushing instruments. They are composed of the triple phosphate of ammonia and magnesia, combined with some phosphate of lime. Other and rarer forms of urinary concretions, are the *carbonate of lime*, *cystic oxide*, and *xanthic oxide* calculi.

Many articles of diet and medicinal agents pass into the urine entirely *unchanged;* such are the alkaline chlorides, phosphates, sulphates, and nitrates. Of these salts, chloride of sodium acts especially as a stimulant to all the processes of tissue metamorphosis, and herein may be found one of the chief uses of this universal constituent in the fluids of all animals. The carbonates of the alkalies, and the caustic alkalies, produce, however, still more powerful effects. The vegetable alkaloids, as quinine, morphia, and strychnia, certain vegetable coloring substances, such as saffron and rhubarb, and many odorous substances, as turpentine, garlic, assafœtida, and valerian, likewise pass unchanged. Nitric, phosphoric, and sulphuric acids also escape, combined with appropriate bases derived from the blood; sulphuric acid displaces phosphoric and this latter acid, the feebler inorganic and organic acids. Most substances, however, undergo a *change* before they enter the urine. Thus, the organic acids, such as lactic, but especially tartaric, citric, malic, racemic, and also acetic acid, and their salts, do not reach the urine as such, but, united with soda or potash, they are converted in the system, into carbonates, which enter the urine. Hence the alkaline condition of this fluid, caused by succulent vegetable diet, and the alkaline urine of the Herbivora. Again, as already mentioned, benzoic acid and the allied cinnamic acid, are first converted into hippuric acid. Organic compounds containing sulphur, produce sulphates in the urine. A great number of substances, on being taken into the stomach, do not reappear in the urine, such as ether, thein, caffein, theobromin, asparagin, amygdalin, musk, camphor, and certain coloring matters, such as cochineal and chlorophyll. Alcohol, though chiefly decomposed in the system, may partly appear in the urine. Of the metallic salts, such as arsenic and antimony, the bases of which can, of course, undergo no change in the body, some appear with great facility in the urine; whilst others enter that fluid with difficulty, or only in minute traces even after long periods of administration; such are gold, silver, mercury, lead, bismuth, zinc, and iron. Alumina is absorbed with difficulty, or not at all, hence it does not appear in the urine.

Water is eliminated with great rapidity from the kidneys. In large quantities, as already stated, it causes, by stimulating the excreting power of the uriniferous tubes, an absolute increase in the amount of urea separated from the body; though relatively, owing to its dilution, a given quantity of urine contains less urea. The diminution in the quantity of urea and uric acid excreted by the kidneys, caused by many agents, such as coffee, tea, alcohol, and tobacco, articles so widely and instinctively adopted by mankind as dietetic substances, has been explained, by supposing that they interfere with, or retard, the metamorphoses of the albuminoid and fatty tissues, and so preserve them from waste. In this way, when taken in moderation, they conserve the strength. The action of creatin and creatinin, so abundant in beef-tea and beef-juice, may be similar. Thein and caffein resemble those substances very closely in composition.

The *rapidity* with which water and substances soluble in it, pass into the urine, after being taken into the stomach, formerly led to the idea that direct channels of communication, passages, or ducts, existed between the stomach and the kidneys, or some other part of the urinary apparatus. Many investigations were undertaken, some even with pretended success, for the purpose of discovering such passages. No such communications, however, exist. Soluble substances pass from the stomach into the circulation, by venous absorption, and are then, after traversing the lungs, conveyed by the renal arteries to the kidneys, in which, by porous diffusion or dialysis, they enter the uriniferous tubules, and so reach the urinary passages. The rate at which this circuitous route through the vascular system, from the stomach to the kidneys, occurs, is adduced as one proof of the rapidity of the circulation of the blood (p. 618). When the stomach is empty, after long abstinence, the time is 1 minute; 4 hours after a meal, it is 2 minutes; $1\frac{1}{2}$ hour after, $6\frac{1}{2}$ minutes; 1 hour after, 14 minutes; and 25 minutes after, 16 minutes. If the test substance be taken with the food, it requires 40 minutes for it to appear in the urine. (Erichsen.)

The affinity of certain substances for the living tissues influences the rate of their passage from the stomach to the kidneys—saline substances, for example, passing more rapidly than coloring matters. The relative diffusibility of the substances may also modify the result. Pigments pass but slowly, indigo and madder requiring fifteen minutes, rhubarb and biliary pigments twenty minutes, logwood and other coloring matters, twenty five minutes.

It has been seen that many substances which are formed in, or belong to, the body, are liable to enter the urine, viz.: pus, fatty matters, certain biliary products, sugar, inosite, leucin, allantoin, tyrosin, sarcin, hæmatin, fibrin, and albumen. If *bile* be no longer separated from the blood in the liver, or if its discharge by the alimentary canal be prevented, it may appear in the urine, as it will in any other secretion or excretion; this happens in certain organic diseases of the liver. But, in the more common form of jaundice, the bile pigments *only* pass into the urine, giving it a dark color. The *sugar* which appears in the urine, in diabetes (p. 748), is not produced in the kidneys, nor does its presence in the urine necessarily imply disease of those organs; a larger quantity than usual being present in the blood, it escapes through the excreting structure of the kidneys. Its increased amount in the blood depends on an abnormal action of the liver, or on the imperfect oxidation of the sugar in the blood, through some defect in the respiratory process. The transitory appearance of sugar in the urine is not of much consequence; but its persistence, in diabetes, is serious. A minute trace constantly occurs in healthy urine, though it escapes ordinary tests. (Brücke.) The presence of albumen in the urine is important, especially if persistent. If temporary, it indicates pressure, or a great attenuation of the blood, or else an increased pressure on the blood in the renal arteries. Thus, drinking enormous quantities of water has been known to produce temporary albuminuria or albuminous urine; on the other hand, albumen is sometimes met with in this fluid after indulgence in very full meals, or in cases where the heart's action is materially increased; or, again, where the aorta is compressed below the renal arteries, or from renal congestion or inflammation, produced either by cold applied to the skin, or by the undue use of diuretics or irritants, such as the Spanish fly; possibly, also, by division of the renal sympathetic nerves. (Krimer.) The occurrence of albuminoid matter, after full meals, may be accounted for by the probable introduction into the blood under those circumstances, of more or less albuminose, which has a higher osmotic tendency than albumen itself; when injected into the veins, it, indeed, appears in the urine. Again, ligature of the aorta, below the renal arteries, in animals, or the forcible injection of blood through those vessels, causes an artificial albuminuria. Persistent albuminous urine indicates some degeneration of the excreting tissues of the kidneys, usually consisting of the so-called granular degeneration, or "Bright's disease," the result of interstitial deposits of an albuminoid, fatty, or amyloid nature. In such cases the lateral pressure of the blood in the capillary vessels of the kidneys is increased, either by the obstruction of the circulation through them, or as a result of the non-performance of the ordinary excreting process. Besides the albumen of the blood, even the plastic fibrinous substance may exude into the uriniferous tubules, and, becoming coagulated in their interior, form, together with altered epithelial cells, or with fatty matter, uric acid, blood or pus corpuscles, little cylindrical masses, known as *casts*, which are washed out of the tubes, and are easily detected in the urine by the microscope. Sometimes the casts consist only of basement membrane. Bright's disease may, however, exist without the presence of albumen in the urine.

To detect bile in the urine, Pettenkofer's test is used (p. 539). Sugar is detected by Trommer's copper test (p. 546), or by boiling with liquor potassæ, which causes a deep brown color when sugar is present. Albumen is detected by boiling the urine, and adding a few drops of nitric acid, to make sure that the urine is not alkaline; certain precipitates, caused by heat, are then dissolved, but an albuminous precipitate remains, as whitish or yellowish flocculi of coagulated albumen. After the continued administration of certain metallic poisons, such as arsenic and antimony, their detection in the kidneys or liver may furnish the means of discovering crime.

As the blood is the most complex fluid proper to the body, being the source of nourishment to the tissues, and also the medium through which the products of their metamorphoses reach the excreting glands, so the urine is by far the most complex of the animal excretions. Its peculiar ingredients display important relations to the gelatinoid and albuminoid principles of the body and of the food, the metamorphoses of which, during the nutrition of the muscular and nervous systems, constitute, with those of the hydrocarbons and carbhydrates consumed in respiration and motion, the characteristic chemical phenomena of animal life. They especially eliminate nitrogen, but also a large amount of carbon, and some hydrogen. The excretion of effete nitrogenous matters by the kidneys may be assisted by the liver; but most of the nitrogenous fatty acids of the bile are reabsorbed. It is by the kidneys that these nitrogenous products of metamorphosis are constantly being removed; and if their function be arrested, grave mischief ensues. Ligature of the ureters is followed by an accumulation of urea in the blood; removal of the kidneys, by an increase of the creatin and the creatinin in the blood, and also, though to a less extent, of urea, which is found in the serum; a urinous odor appears in many of the secretions. In the uræmic poisoning which depends on disease of the kidneys, the urea, ceasing to be excreted through them, is detectible in large quantities in the perspiration, and also in the vomited matters. The urea itself, or the carbonate of ammonia resulting from its decomposition, then easily detected in the breath, circulates through the brain and spinal cord, and causes imperfect respiration, convulsions, coma, and death.

The Kidneys and the Urine in Animals.

These important glands, so essential to the animal economy, are well developed in all the Vertebrata, forming, as in Man, two symmetrical organs situated at the back of the abdomen. In Mammalia, as in Man, the kidneys are composed of an external cortical substance, consisting chiefly of convoluted tubuli, and of an internal medullary substance in which the tubuli are straight.

The kidneys of many Mammalia exhibit the typical bean shape, but they are often more rounded than in Man, as in the sheep, pig, and dog. They are sometimes more or less lobulated. In the ox, the kidney is sublobulated, being marked by fissures between the pyramids, which form the lobules, remaining, however, united beneath the divided cortical portion. In certain Carnivora, as in otters, seals, and bears, the pyramids, each covered by its own cortical layer, are separated by deeper fissures, into which even the capsule of the kidney penetrates, so that the lobules form clusters of distinct polyhedral masses attached to the separate infundibula of a much-ramified ureter. The kidney is most deeply lobulated in the Cetacea. In the early embryonic condition of this organ in all Mammalia, the lobulated character is present; in the Cetacea and certain Carnivora, it persists, and forms the so-called compound kidney; in other animals, as in the ox, the lobules partly coalesce; lastly, in the sheep, dog, and Man, they completely unite, as development advances. Indeed, a lobulated or ramified condition seems to be a less developed form of many glands than the massive shape, as is illustrated by the liver, pancreas, spleen, and thymus in animals. Lobulation of the lung, however, is a sign of higher development. Subordinate peculiarities exist as to the mode in which the papillæ of the kidneys are connected with a simple or much-subdivided ureter.

In *Birds*, the kidneys no longer present an obvious distinction into a cortical and medullary substance, and the gland tissue is much less firm than in the Mammalia. In Birds, these organs are of considerable length, occasionally blended together, in places, across the middle line; they extend from the posterior border of the lungs, down to the lower end of the rectum, and are moulded into recesses in the bones of the lower part of the spinal column. The kidneys of Birds are, therefore, slightly lobulated. The uriniferous tubuli of each lobule are arranged in bundles or tufts, which end in the outer or superficial part, by dichotomous tubes; the symmetrical ureters proceed from the abdominal surface of the glands, receiving the uriniferous tubules directly, without the formation of infundibula, or of a pelvis. They open below, in the upper and back part of a dilatation found at the lower end of the alimentary canal, named the cloaca, where there is a sort of recess, which has been regarded as representing an imperfect bladder.

In *Reptiles*, the kidneys are very large, occupy the same general position as in Birds, and are usually of great length. In the turtles, tortoises, and lizards, they are symmetrical, and fixed to the lumbar and pelvic regions; but in Serpents, the right kidney is placed higher than the left, as if for convenience; they extend along the greater part of their elongated and flexible spine. The kidneys present no distinction of cortical and medullary substance; but they are deeply lobulated, and loosely connected with the surrounding parts. The ureters are long and narrow, and end in a sort of cloaca. The *tubuli uriniferi* are reduced to convoluted, or even short, straight cæcal tubes, arranged in converging bundles, or placed transversely. In the crocodile, the convoluted tubuli are so distinct as to appear like a cortical layer.

In *Amphibia*, the kidneys are flat and broad at their hinder end, but become very narrow at their anterior part, and thus show an approximation to their form in Fishes. Numerous ducts proceed from their inner border, to a long slender ureter, which opens into the cloaca.

In *Fishes*, the kidneys are proportionally large; they vary in shape in different species, but, as a rule, are narrow, and of extreme length, being attached beneath the bodies of the vertebræ, along the whole or the greater part of the abdominal cavity, above the air-bladder when that organ exists. There is no distinction of cortical and medullary substance, and tufts of slightly tortuous urinary tubuli, or completely straight cæcal tubes, end at once in narrow elongated ureters, which usually open on each side, into the cloacal portion of the rectum, but which sometimes first coalesce. In the low Myxinoid fishes, the upper portion of the kidneys is much attenuated, and presents a complete unfolding of the gland structure; the tubuli, instead of being long and aggregated, are short, distinct, and commence by little dilatations, into which the Malpighian glomeruli project. In the amphioxus, the kidney has not been distinctly made out, though it is probably represented by a narrow gland-like mass placed near the abdominal pore.

The kidneys in Birds, Reptiles, Amphibia, and Fishes, may be considered as composed entirely of cortical substance; they invariably contain Malpighian corpuscles, or arterial glomeruli, which are usually scattered through the gland, and, as usual, project into dilatations of the uriniferous tubuli. These bodies vary in size, apparently in accordance with the size of the animal, as well as in different Classes. Thus they are larger, $\frac{1}{70}$ and $\frac{1}{80}$ of an inch, in the lion and horse, than in Man, $\frac{1}{100}$; they are much smaller in the guinea-pig, cat, and mouse, $\frac{1}{200}$ to $\frac{1}{250}$ of an inch; they are small in Fishes, $\frac{1}{200}$, and Amphibia, $\frac{1}{250}$, but smallest of all in Reptiles, $\frac{1}{240}$ to $\frac{1}{400}$. In the pointed renal lobules of the boa, they are smaller in the narrow than in the wider portions of each lobule. In the simpler kidneys of Fishes, they are represented by small vascular plexuses. Cilia are found in the uriniferous tubuli in the Cold-blooded Vertebrata; they commence at the neck of the capsules into which the Malpighian bodies project, and extend for a short distance along the tubuli, sometimes throughout their whole length. The current which they produce as seen after death, is towards the orifices of the tubules. Cilia have not yet been distinctly seen in Birds or Mammalia.

In Birds, Reptiles, Amphibia, and Fishes, the renal arteries, instead of being two in number as in Mammalia, are numerous, and are derived from adjacent branches of the aorta, or from the aorta itself. Besides this, the kidneys in these Classes, receive more or less venous blood from the hinder limbs in Birds and the four-footed Reptiles and Amphibia, and from the hinder parts of the body in Ophidia and in Fishes. The rest of the blood from the hinder portion of the body, usually passes partly to the vena cava, and partly to the vena portæ; in Reptiles, Amphibia, and most Fishes, it goes chiefly to the latter; in a few Fishes all the blood from the hinder part of the body proceeds to the kidneys.

The fact that the kidneys in Birds, Reptiles, Amphibia, and Fishes, receive a supply of venous blood was first noticed by Bojanus, but the detailed arrangement of the afferent veins was fully investigated by Jacobson. These renal portal veins become more numerous in the lower Vertebrata. After entering the kidneys, they quickly subdivide, and end in the vascular plexuses which surround the uriniferous tubuli. The Malpighian bodies still receive arterial vessels only, but give off efferent vessels which join the plexuses around the tubuli. In the lower Vertebrata, accordingly, the special urinary products, like the bile products, are, in all cases, excreted from venous blood; and the small quantity of arterial blood which enters the kidneys, first passes through the vascular tufts of the Malpighian bodies, and so becomes modified, before it reaches the plexuses around the proper excreting tubuli, in the same manner that the hepatic arterial blood becomes venous, before it reaches the intra-lobular plexuses of the liver. As already stated, the existence of this portal arrangement of the vessels in the kidneys of Birds, Reptiles, Amphibia, and Fishes, supports the view, that in Mammalia, also, the renal arterial blood becomes venous in traversing the vessels of the glomeruli, before it serves for the excretion of urinary constituents. The pasty or solid character of the urine in Serpents, may depend, not only on the small size of the glomeruli, but also on the fact that these animals swallow little or no water.

Excretory glandular organs, having the function of kidneys, exist at least in the higher Non-vertebrate animals; but owing to the different plans of construction in these Subkingdoms, it is impossible to recognize much, if any, resemblance of position or structure, between them and the renal organs even of the lowest Fishes. But the unity of the vito-chemical processes of animal life, is proved by the detection of urinary products in some of these excretory organs in the Mollusca, Annulosa, and Cœlenterata. Uric acid has been found in the two former Classes, and guanin in the last.

In the *Mollusca*, the organs which represent kidneys are not connected by ducts with the alimentary canal. In the Cephalopods, remarkable spongy masses of follicles exist around the large branchial veins, and discharge themselves, by numerous apertures, into the branchial cavity; these are supposed to act as renal emunctory organs, their excreted fluid containing uric acid. In the Gasteropods, a smaller follicular organ, also containing that acid, is usually found in the neighborhood of the heart, and its ducts open near the intestinal orifice, generally into the branchial cavity. In the Lamellibranchiata, a similar organ, but, in most cases, less distinct, is also found near the heart, close to the lower end of the intestine, opening into the cavity of the mantle. In the *Mulluscoida*, distinct renal organs have not yet been recognized. Amongst the *Annulosa*, the Insecta, Myriapoda, and Arachnida, have excretory organs believed to be renal, consisting of long tubes, often beginning by clusters or tufts of vesicles; they are sometimes few, as in Myriapoda, sometimes very numerous, as in the higher Insects. As in the Vertebrata, they open into the lower part of the intestine, or even close to its orifice; sometimes the principal duct is dilated near its lower end, as if to form a urinary bladder. The colored fluid discharged by the lepidoptera, on their emerging from the chrysalis, proceeds from these vessels, and contains uric acid. No such renal organs are found in the Crustacea, which are aquatic. In the *Annuloida*, in which they are likewise absent, the water-vessels may have some excretory function, and eliminate urinary products.

In certain of the *Cœlenterata*, small clusters of cells projecting into the body cavity, and containg guanin, are regarded as renal organs; but in the simplest forms of these animals, the excretion of the products of the decomposition of albuminoid substances is probably accompanied by the external and internal surfaces of their hollow bodies.

Lastly, in the minute *Protozoa*, such products must also be eliminated by the general surface.

Special Secretions in Animals.

Certain secretions or excretions, in animals, may perhaps be regarded, not merely as serving a peculiar purpose in the economy, but also as fulfilling an emunctory office, eliminating from the system substances which might be as injurious to animal life as urea and uric acid. Amongst such, may be mentioned the castor of the beaver, the musk of the musk-deer, the peculiar secretion of the civet-cat, and those of other Mammalia, also the venom of Serpents, the acrid secretion of the skin of the toad, the ink of the cuttle-fish, which yields the sepia color used by painters, the poisons of the stings of the bee and the wasp, the sugar secreted by aphides, the odoriferous excretions of the bugs and many other beetles, the poison in the tail of the scorpion and the mandibles of the spider, the odoriferous exudations of the lumbrici, and even the threads of the sea-nettles. Examples of special secretion are also met with in those glands which in many caterpillars supply the silk used in progression or for the cocoons, in the spinneret glands of the Spiders, the cement gland of the Cirrhopods, and the glandular structures which secrete the byssus of certain Lamellibranchiata.

However different and specialized may be the actions of the various glandular organs in the Animal Kingdom, which yield such widely different products, they are all based on a common plan of structure and function. Even in the highest animals, and in Man, their physiological relationship is evidenced by an occasional tendency to a vicarious action, in which one gland or several glands take on the suspended function of another.

THE SKIN AND ITS EXCRETIONS.

By means of its sebaceous and sudoriferous glands, the skin secretes and excretes fatty matter, and the perspiration or sweat. Besides this, it exhales water from its surface, and throws off certain quantities of carbonic acid gas.

The *sebaceous* or *oily matter*, formed by the so-called sebaceous glands (p. 361; Fig. 69, *a*), consists of a mixture of olein, saponified fat, cholesterin, a small quantity of an unnamed albuminoid substance, and a few epidermic cells. Its ashes abound in earthy phosphates. The fat is either derived from the fatty matter of the plasma of the blood, or more probably from the metamorphosis of the albuminoid contents of the epidermic cells of the sebaceous glands. It is poured out, partly on the surface of the skin, but more commonly into the interior of the hair follicles, or even into the most minute ones. It contributes to soften and render flexible both the hairs and the skin, and, by protecting the latter from the action of water or aqueous solutions, it renders the skin more effectual as a defensive organ. The so-called *ceruminous* and *Meibomian* glands of the ear and eyelids, may be regarded as special modifications of sebaceous follicles.

In all Quadrupeds which possess hairs, sebaceous or oil glands exist; the *glandulæ Uropygii*, or caudal glands, of Birds, supplying the fatty secretion with which they anoint their feathers, are highly developed sebaceous glands.

The epidermic tissues generally, viz., the cuticle, nails, and hairs, have been viewed as solid excreted substances. When worn, cut, shed, or desquamated, they undoubtedly rid the economy of a large amount of nitrogenous, sulphurous, and ferruginous matter. The continual loosening of epithelial cells from the gastro-pulmonary cavities, must serve a similar office.

The *sudoriferous*, *sudoriparous*, or *sweat glands*, are present, in larger or smaller numbers, in all parts of the skin. They are small, rounded, pinkish bodies, placed immediately beneath the true skin, and average about $\frac{1}{6}$th of a line in diameter. Each sweat gland consists of a fine tube, closed and coiled up into a ball at its deeper end, from which a straight part of the tube, or duct, passes up through the cutis and cuticle, and opens by a somewhat widened orifice on the surface. When the cuticle is thick, as in the palms and soles, this tube passes through it in a spiral manner (Fig. 66, 5, 6). The whole tube, when unrolled, measures about $\frac{1}{4}$th of an inch in length, and about $\frac{1}{300}$ of an inch in width. This tube consists of an outer vascular coat, prolonged from the cutis, and of an epidermoid lining, continuous with the cuticle; the spiral portion is composed of the latter only. Two coiled tubes may unite into one duct. When a sweat gland is destroyed, it is not reproduced. In some situations the sweat glands are of large size, as in the axillæ, where they measure nearly two lines in diameter, are of a darker red color, are composed of branched tubes, and secrete a thick, exceedingly acrid, and odorous fluid. In the palms and soles, the openings of the sweat glands, the so-called *pores* of the skin, are found on the papillary ridges; in other parts, they are scattered over the surface. They are most numerous on the palm of the hand, where 2800 orifices are found on a square inch; they are fewest on the back of the neck and trunk. Non-striated muscular fibres, arranged longitudinally, exist in the vascular coat of the ducts of the larger sweat glands. (Kölliker.)

The *perspiration*, or *sweat*, which is excreted by the *sudoriferous* or *sudatory* glands, is not the only watery exhalation from the skin; for water is undoubtedly exhaled from the integument generally, as well as from the sweat glands. The perspiration is said to be *insensible* when no visible moisture is discernible on the skin, and *sensible* when it is so discernible; but there is no real difference between them; in the former case the fluid part evaporates as fast as it exudes from the orifices of the sweat glands, whilst, in the latter, it remains for a moment or so, in minute transparent colorless drops.

The sweat usually contains about 97.5 of water and 2.5 of solid matter, but sometimes less than 1 per cent. of the latter. The organic constituents are little more than half of this, and are composed chiefly of fat, which is probably almost entirely derived from an admixture of the secretion of the sebaceous glands; but the palms of the hands and the soles of the feet are more or less greasy, although no sebaceous follicles exist in that part of the skin. Besides this, the organic matters of the perspiration contain an albuminoid substance, the nature of which is unknown, and acids which give it an acid reaction, by some supposed to be lactic acid, but now usually regarded as a mixture of a peculiar nitrogenous acid, named *sudoric*, with the volatile acetic, metacetonic, formic, and butyric acids, together with the fatty caprylic and caproic acids. Some of these acids are combined with alkalies. Almost one-fourth of the solid matter is urea, the total daily quantity having been estimated at about 150 grains, which would yield about seventy grains of nitrogen. This urea is easily decomposed, and gives rise to ammoniacal salts, such as were described by Berzelius, for no ammonia is found in perfectly fresh perspiration. The inorganic matters are chiefly common salt and chloride of potassium, phosphate of soda, and traces of earthy phosphates, and iron. On burning the total solids, some sulphates are formed, indicating the presence of sulphur in some combination, probably with the organic matter. A certain quantity of epidermic cells and extraneous substances also occur in the residue. The odor of the perspiration depends partly on the volatile acetic, formic, and various fatty acids, but also perhaps on special, but unknown, volatile odorous substances. Some of the odor may be due to decomposing urea. In certain diseases, in which the excretion from the kidneys is seriously diminished, or altogether suppressed, as in Bright's disease and cholera, when the urea and uric acid are retained in the blood, large quantities are frequently excreted by the skin, probably chiefly by the sudoriferous glands. Besides the above-named substances, alcohol in small quantity, sugar, albumen, biliary matters, and other substances, have been found in the perspiration.

The *uses* of the perspiration are twofold: first, to get rid of a certain quantity of water from the system; and secondly, to eliminate from the body certain special products of chemical metamorphosis.

Many attempts have been made to determine the average quantity of fluid exhaled by the skin, under ordinary circumstances, in twenty-four hours, and the variable quantities which are given off under different conditions. In the earlier experiments, the losses, by exhalation both from the skin and the lungs, were confounded, the body being weighed together with the food and drink taken in twenty-four hours; at the end of that time, the weight of the body was again taken, and also that of the intestinal and renal excreta; the difference in these two totals, gave, for the amount of cutaneous and pulmonary exhalation together, $\frac{5}{8}$ths of the total loss of weight of the body. (Santorini.) By enveloping the body in an impermeable oil-silk bag, so as to condense and retain the water of the cutaneous exhalation, it was found that, in an adult, about 30 oz. are daily exhaled by the skin, whilst at the same time, 15 oz. are given off by the lungs, making a total daily loss, by both skin and lungs, of 45 oz. (Seguin.) The total loss has, however, been estimated at 45½ oz. in the autumn, 44 oz. in summer, and 37 oz. in spring, in a person under the average size. (Dr. Dalton.) Other estimates give an average total loss of 57 oz., 51 oz. in the winter, and 63 oz. in the summer.

The quantity of perspiration exhaled by different parts of the body differs widely. Its general quantity is influenced both by intrinsic and extrinsic conditions; thus it is augmented by increased vascularity of the skin, by a higher temperature of the body, by a quicker circulation, and therefore by exercise and effort generally. Perspiration may also be induced by additions to the clothing or covering of the body, and likewise by breathing in a confined space; it is also increased by peculiar conditions of the nervous system, as by certain depressing emotions and syncope, all of which tend to relax the skin and its bloodvessels. It is, on the other hand, diminished or almost entirely arrested in febrile conditions and certain forms of excitement, and, it is said, also by the use of coffee. It is increased by taking food generally, but more particularly after dinner. The secretion is stated to be most active about noon, and least so in early morning. It is also augmented during sleep.

Of the external conditions which modify the quantity of the perspiration, by far the most important are the temperature and hygrometric condition of the atmosphere. Thus, in warm air, which increases the activity of the cutaneous circulation, the perspiration is increased, whilst cold air has the opposite effect; again, dry air increases the perspiration, whilst damp air diminishes it. Simple warmth acts by increasing the vascular action through the skin; whilst dryness operates by maintaining a constant evaporation from the cutaneous surface; on the other hand, cold diminishes the vascularity of the skin, and dampness of the air impedes evaporation. The combination of moisture with heat, however, increases the exhalation by the skin, which then appears in large drops. Motion in the air, whether warm or cold, dry or moist, increases the relative amount of perspiration, by carrying it off more quickly. The perspiration is said to be diminished by increased atmospheric pressure. This excretion is also augmented by large quantities of drinks, especially when taken warm; by so-called sudorific medicines, such as nitre, Dover's powder, and vinegar; by electricity; and also by hot baths, whether water-baths, vapor-baths, or hot-air baths, especially when, as in the Turkish and Roman baths, friction and shampooing are superadded. Certain curious local sweatings have been noticed, affecting the head alone, or the feet and hands, or even one side of the face only, phenomena which probably are due to some loss of power in the vasi-motor nerves of the arteries of those parts, giving rise to dilatation of the vessels, increased vascularity, and increased secretion. Suppression of the cutaneous exhalation and excretion, is more or less dangerous, causing either local internal congestion or inflammation, or general poisoning of the blood and fever, from the retention of effete matters in the system. Hence the ill effects of sudden cold, or chill to the surface, especially after previous overheating of the body to the point of fatigue, and with the accumulation of effete substances of waste in it. The chief use of this copious exhalation of water from the skin, as will be explained in the Section on Animal Heat, is that of regulating the temperature of the body, under variations of external temperature.

The mutual balance between the respective quantities of the renal and cutaneous exhalations, under different physical conditions, chiefly those relating to the temperature and hygrometric condition of the air, is shown by the facts, that in cold weather the skin exhales less, and the kidneys excrete more fluid, whilst in warm weather the skin eliminates more and the kidneys less. The skin is sometimes said to regulate the quantity of fluid given off by the kidneys, and the quantity of fluid left in reserve in the blood, and the soft tissues generally; but the kidneys should rather be regarded as the true regulators in this matter. The skin, and also the lungs, are exposed to external influences of temperature, and to the relative hygrometric state of the air, which must affect the quantity of their exhalations; but the kidneys, being placed in uniform conditions, are sensitive self-acting regulators, operating through stimulation of the vasi-motor nerves, which govern the state of the arteries and vessels of the glomeruli, and determine the supply of blood. In certain conditions, moreover, the renal and cutaneous excretions, instead of being vicarious as to quantity, are simultaneously increased or diminished.

The office of the perspiration, in removing effete matter from the blood, is, in the first place, evident from the composition of its solid constituents, although these are comparatively scanty. Supposing 30 oz. of perspiration to be the daily quantity excreted, the amount of urea and of other peculiar solids thus eliminated, would be about $\frac{1}{3}$d oz.; whilst the daily quantity of solid urinary products amounts to from 2 oz. to $3\frac{1}{2}$ oz.

As an organ of excretion, however, the skin further eliminates carbonic acid gas. The skin, indeed, is, to a slight extent, even in Man, a respiratory membrane, giving off carbonic acid, and actually absorbing oxygen. The quantity of carbonic acid gas exhaled by the comparatively dry cutaneous surface of the human body, is, of course, relatively to that given off by the lungs, very much less, and has been variously estimated at from $\frac{1}{30}$ to $\frac{1}{60}$ (Scharling), at $\frac{1}{38}$ (Scharling and Hannover), and at $\frac{1}{100}$ (Edward Smith), of that given off by the proper respiratory organs, the lungs. It is stated that in regard to the skin, a little more carbonic acid is given off than oxygen is absorbed, which is the reverse of what happens in the lungs; but the estimation of the quantity of oxygen absorbed is extremely difficult. The same remark applies to the nitrogen, a minute trace of which is said also to be taken up by the skin. The activity of this cutaneous respiratory process, as it must be called, is considerably increased by exercise. The quantity of nitrogenous matter daily removed in the shape of desquamated epidermic cells, is said to be about 11 grains. A partial interference with the excretory function of the skin, causes headache, lassitude, and febrile reaction; a more serious disturbance, by over-exciting the kidneys, will bring on temporary albuminuria.

The preceding facts sufficiently explain the high importance of cleanliness of the skin, for the preservation, not only of comfort, but of health. Daily ablutions by sponging, and the occasional use of the tepid bath, are of great efficacy in the maintenance of a pure condition of the blood.

The Cutaneous Excretion in Animals.

The sudoriferous glands of the higher Vertebrata, and the cutaneous glandular organs of the lower Vertebrate, and Non-vertebrate animals, have been already described (p. 372).

When the skin of a rabbit is shaved, and the body subsequently coated over with varnish impenetrable to water and gases, death ensues from asphyxia in from six to twelve hours, a condition which has been named *cutaneous asphyxia.* The symptoms are depression, difficulty of breathing, lowering of the temperature, congestion of the tissues and organs with dark blood, and ultimate death. The arrest of cutaneous respiration may partly account for this form of death, with accumulation of carbonic acid in the blood; but doubtless also, it depends on the shutting in of peculiar cutaneous products. The fatal result can scarcely be referred to the non-exhalation of water. In the soft-skinned Amphibia, the entire cutaneous surface exhales carbonic acid, and absorbs oxygen; in the frog, for example, after removal of the lungs, $\frac{1}{4}$ cubic inch of carbonic acid gas has been excreted from the skin, in eight hours. (Bischoff.) This experiment is performed by putting the animal, after deprivation of its lungs, under a glass receiver filled with air, and placed over mercury; the carbonic acid is absorbed by lime-water, and so measured. The skin of the frog, which is moist and full of capillary vessels, presents conditions favorable to the solution and diffusion of gases in contact with it, by a mechanism to be explained in the next Section. Probably nearly as much carbonic acid is eliminated by the frog, from its cutaneous surface, as from its comparatively simple lungs.

In the soft-skinned, aquatic, Non-vertebrate animals, the integument is often an adjuvant, or the chief, or sole, respiratory surface, being for that purpose frequently ciliated.

RESPIRATION.

The *arterial* blood in passing through the systemic capillaries, serves the purposes of nutrition, stimulation, secretion, and excretion, and the blood, as it leaves those capillaries, is tainted by the products of venous absorption. In the various changes which it undergoes, the arterial blood both loses and acquires certain substances, and so becomes *venous.* Thus changed, it returns to the heart, and, being now conveyed through the pulmonary capillaries, is there rapidly restored to its arterial condition. This conversion of venous into arterial blood, is the *immediate* object of the respiratory process. In it, oxygen is absorbed by the blood, whilst carbonic acid, together with some watery vapor, is given off. The source of the oxygen is the atmosphere; the carbon of the carbonic acid is derived from the blood and tissues, themselves supplied by the food. The chemical union of the oxygen with carbon, and also with hydrogen, in the system, maintains the movements and the temperature of the body, and is the source of its nervous power and electricity.

The function of *respiration*, therefore, has for its immediate effect, the purification of the blood, and for its ultimate uses, the production of Animal Heat, Motion, and Nervous Energy.

In plants, as elsewhere mentioned, the respiratory process is reversed. Under the action of light, the carbonic acid and water taken up, partly by the leaves, but chiefly by the roots, are decomposed in the leaves; the oxygen is liberated, whilst the carbon and hydrogen, with the hydrogen and nitrogen from ammonia, together with sulphur and phosphorus, combine to form the proximate constituents necessary for the food and fuel, which nourish animals, and support their respiratory and other vital processes.

We have just seen that the skin is the seat of a feeble respiratory process, consisting of an interchange of oxygen and carbonic acid. A small amount of oxygen may also be absorbed, and of carbonic gas exhaled, at the mucous surfaces of the stomach and intestines; for atmospheric air is swallowed, mixed with the saliva and food, and dissolved in the drink. But in animals generally, excepting in the very lowest, special *respiratory organs*, often consisting of a very complicated apparatus, are present.

The respiration of animals is performed, sometimes in air and sometimes in water, the former being termed *aerial* and the latter *aquatic*, *respiration*. The Mammalia, including Man, all Birds, Reptiles, and Amphibia, amongst the Vertebrata, the Pulmo-gasteropods belonging to the Mollusca, and the Insecta, Arachnida, and Myriapoda amongst the Annulosa, are *aerial breathers*, and are provided either with complex hollow organs named *lungs*, with simpler *air sacs*, or else with minute air-tubes, or *tracheæ*, all these organs communicating directly with the *atmosphere*. A certain number of the Amphibia, all the Fishes, the Mollusca generally, except the pulmonated Gasteropods, all the Molluscoida, the Crustacea amongst the Annulosa, and all the Annuloida, Cœlenterata, and Protozoa, are *aquatic breathers*, and are provided either with projecting organs named *branchiæ* or *gills*, sometimes external, but more commonly concealed, or with internal *ciliated sacs* or *canals*, or with external *ciliated processes*, *discs*, or *surfaces*, always in contact with *water*.

In aerial respiration, the source of the oxygen taken into the body, is the atmosphere, into which the carbonic acid is given off. In aquatic respiration, although the breathing is subaqueous, so that the oxygen is taken up from, and the carbonic acid given off into, the water, still the ultimate source of the oxygen is the atmospheric air dissolved in that medium. The solvent power of water for air is very great, and owing to the greater solubility of oxygen than of nitrogen in water, the air held in solution in this fluid contains an unusual proportion of oxygen.

The great importance of the function of respiration to animal life is shown by the fact that its interruption, by mechanical or chemical interference with the respiratory organs, is speedily followed by death. Air-breathing animals are quickly suffocated by strangulation, by immersion in water, by placing them under the receiver of an air-pump, and then exhausting it, by giving them only a limited supply of air, or by making them breath gases not containing free oxygen. Aquatic breathers are as quickly destroyed, if the fluid by which they are surrounded has been deprived of air by boiling, or by placing it under the receiver of an air pump, and then exhausting it.

In studying the respiration of Man, and the Mammalia generally, we have to consider the structure of the organs of respiration, *i. e.* of the thorax and its muscles, the air passages and the lungs; the mechanism of respiration, or the respiratory movements by which air is alternately drawn into, and expelled from, the body; the movement of the air in respiration, and the capacity of the lungs; the changes which the air undergoes during respiration; the changes produced by this process upon the blood and the tissues; the circumstances which modify the respiratory interchanges, including the phenomena of asphyxia, and the effects of breathing bad air; and lastly, the organs and functions of respiration in animals. Afterwards, it will be necessary to consider the phenomena of Animal Heat, Light, and Electricity; and to discuss, in a separate Section, the interesting questions relating to the Dynamics of the Animal Economy.

THE ORGANS OF RESPIRATION.

The Thorax.

The *thorax* (p. 31, Figs. 10, 13, 14) is an osseo-cartilaginous framework filled in with soft tissues, which contains and protects the central organs of respiration and circulation. It corresponds with the dorsal region of the spine. In front, it is formed by the sternum and the cartilages and anterior parts of the ribs; behind, by the dorsal vertebræ and posterior portions of the ribs; and at the sides, by the remainder of the ribs. Between these solid parts are the intercostal muscles, which are overlaid in parts by other muscles.

The cavity of the thorax is conical, being narrow above and broad below. Its upper opening, inclosed between the first dorsal vertebra, the first ribs, and the top of the sternum, is wider transversely than from front to back; its plane inclines downwards and forwards. The lower opening, bounded by the ensiform cartilage, the last dorsal vertebra, and the lower ribs or their cartilages, is much larger than the upper one. It is also wider from side to side than from front to back, but its plane inclines downwards and backwards, so that the thoracic cavity is much deeper behind than in front.

The upper opening transmits—besides certain muscles of the neck, the large bloodvessels of the head and upper limbs, numerous nerves and lymphatics, the thoracic duct, and the œsophagus—the principal air-tube, the *trachea*, or windpipe, which leads to the lungs; the summits of the two lungs ascend beyond this opening. The lower opening is closed by the musculo-tendinous, movable structure, named the *diaphragm*, which is itself arched, and reaches higher up on the right side; this opening transmits the œsophagus, the great vessels, the thoracic duct, and the vagi and certain sympathetic nerves.

The Air-Passages.

The nose, pharynx, and larynx, have already been described. The *trachea*, or windpipe, placed in the middle line, descends from the larynx, on a level with the fifth cervical vertebra, to opposite the third dorsal vertebra, where it divides into two smaller air-tubes, named the *bronchi*, one for each lung. The trachea (Fig. 110, 1) is about $4\frac{1}{2}$ inches in length, and from $\frac{3}{4}$ to 1 inch in width; it is wider in the male than in the female. Its anterior surface and sides are convex; its posterior surface is flattened. It is overlapped at its upper part, in front and at the sides, by the isthmus and lobes of the thyroid body;

Fig. 110.

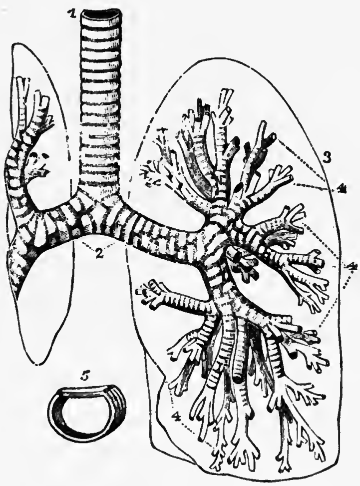


Fig. 110. Air-tubes of the human lungs, dissected out, and seen from the front. 1, trachea or wind-pipe. 2, the right and left bronchi, the right being the wider, the left the longer of the two. 3, outline of the left lung collapsed. 4, bronchia, or bronchial tubes in the lung, cut short. 5, transverse section of a portion of the trachea, showing the incomplete C-shaped rings, with the flat membranous part behind.

it is also covered by certain muscles and vessels of the neck, and is concealed, lower down, by the upper part of the sternum and by the remains of the thymus gland. In the thorax, the large bloodvessels are in front of it, but in the neck, it is placed between them. Behind, its flattened surface rests on the œsophagus, by which it is separated from the spinal column. Its lower thoracic portion is placed in the space known as the posterior mediastinum, situated between the lungs.

The trachea is composed of from sixteen to twenty independent, transverse, incomplete hoops or rings of cartilage, held together by an intermediate fibrous coat, within which are muscular and elastic fibres and a mucous lining membrane.

The cartilages are flattened bands, incomplete behind, each being shaped like the letter C. (Fig. 110, 5), with its open part turned backwards. The first cartilage, which is suspended to the cricoid cartilage of the larynx, is the broadest; the last cartilage is V-shaped. The fibrous coat not only connects the cartilages together, but covers both their outer and inner surfaces; behind, where the cartilages are absent, this membrane is continuous. An external layer of longitudinal unstriped muscular fibres is found connected with the fibrous membrane and with the cartilages; whilst an inner transverse set extends between the ends of the cartilages. Bundles of elastic fibres are placed immediately beneath the mucous membrane; at the posterior flat membranous part of the tube they are seen as yellow longitudinal bands. The mucous membrane, continuous with that of the larynx and bronchi, has a columnar ciliated epithelium. Numerous tracheal mucous glands are found embedded in the walls of the tube, especially at its back part. Its nerves are derived from the pneumogastrics and the sympathetic.

The *right bronchus* measures about 1 inch in length; it is wider, and has a more horizontal direction than the left bronchus; it enters the root of the right lung, opposite the fourth dorsal vertebra. The *left bronchus* is about twice as long as the right one; it is, however, narrower, and passes obliquely downward beneath the arch of the aorta, and in front of the œsophagus, thoracic duct, and descending aorta, to enter the root of the left lung, opposite the fifth dorsal vertebra.

The structure of the bronchi is similar to that of the trachea; in front and at the sides they are convex, and strengthened with incomplete hoops of cartilage, but behind, they are flat, membranous, and muscular. The cartilages are narrower and shorter than those of the trachea; in the right bronchus, there are from six to eight, and in the left, from nine to twelve.

The Lungs.

The lungs, Fig. 13, *l*, *l*, are two in number, and occupy, *completely* and *accurately*, the lateral or pleural chambers of the thorax, one on each side of the pericardium and heart, *h*. Each lung is free in all directions, except at a part of its inner surface, which is connected, by means of the bronchi and the pulmonary arteries and veins, with the trachea and the heart, Fig. 111.

The lungs are porous, spongy organs, the tissue of which is so elastic, that, although they fill the closed pleural chambers, they collapse more or less, when the thorax is laid open. If squeezed, they give rise to a peculiar sensation called *crepitation*, owing to the air which is contained in them. Their size and weight present great variations, depending on their state of inflation, and the quantity of blood in their vessels, or of serum in their tissue. The average weight of the two lungs together is, however, about 42 ounces, the right lung being about 2 ounces heavier than the left; they are larger in the male than in the female; they are, moreover, heavier, their proportion to the body being as 1 to 37 in the former, and as 1 to 43 in the latter. Owing to the air in the lungs, they float entirely, or even in portions, in water; the specific gravity of their substance ranges from 345 to

746, water being 1000. The *color* of the lungs, varies at different periods of life; in the newly born infant, they are of a pinkish white; in the adult they are darker, and become mottled with deep slate-colored spots, patches, or lines, which increase in number and assume a deeper hue as life advances, becoming in some individuals, even black.

The surface of each lung is invested by a thin, smooth, transparent, elastic, serous membrane, named the *pleura*, which passes into certain fissures upon the surface of the lungs; at the root of the lungs it is reflected upon the inner surface of the corresponding *pleural chamber* of the thorax, the whole of which it lines, forming a closed sac (see p. 31). The parietal portion of this membrane partly lines the sides of the thorax, where it forms the *costal pleura;* but in the middle line, it covers a portion of the pericardium, and other parts, and touches the opposite pleura; above, it closes in the upper opening of the thorax, reaching higher than the first rib; below, it lines the diaphragm. A triangular duplicature, forming the broad ligament of the lung, passes down from the root of the lung to the diaphragm, and serves to retain the lower portion of the lung in position. The free and moist surfaces of the parietal and pulmonary portions of the pleura, touch each other. If serous fluid, blood, pus, or air should collect between them, the *cavity* of the pleura becomes evident, and the diseases known as hydrothorax, hæmothorax, empyema, or pneumothorax are developed. The right and left pleuræ are quite distinct from each other. The place where they come into contact, is just above the middle of the sternum; here they are connected together by areolar tissue, but in other parts of the middle line, they are separated from each other by an interval, called the *mediastinum*, in which all the parts contained in the thorax, except the lungs, are lodged. The right pleural chamber is shorter and wider than the left.

Each lung, as well as the pleural chamber into which it accurately fits, is of a conical shape, and presents an apex, a base, an outer and inner surface, and an anterior and posterior border. The *apex* is blunt, and projects into the neck, from an inch to nearly an inch and a half above the first rib. The *base* is broad and concave, and rests on the convexity of the diaphragm; its margin is thin, and passes between that muscle and the wall of the chest; it reaches much lower down at the outer side and behind than it does in front. The *outer surface*, smooth and convex, is in contact with the walls of the thorax, and is of greater depth behind, than in front. The *inner surface* is concave, being adapted to the pericardium and heart, behind which it presents a depression, called the *hilus*, where the bronchi and pulmonary vessels forming the root of the lung, pass in and out. The *anterior borders* of the lungs are thin, and partly overlap the pericardium, that of the right lung reaching to the middle of the whole length of the sternum, that of the left lung doing so only as low as the fourth costal cartilage. Above this point, the anterior borders of the two lungs are merely separated from each other by their pleural membranes; but below it, the anterior border of the left lung forms, over the pericardium and apex of the heart, a V-shaped *notch*, the base of which is turned to the middle line (Fig. 13). The *posterior border* of each lung, much longer than the anterior, is broad and rounded, and occupies the deep groove on either side of the vertebral column, reaching below, between the ribs and the diaphragm.

Each lung is divided by a deep fissure, into an *upper* and *lower lobe.* This principal *fissure* extends from the posterior border of the lung near the apex, obliquely downwards and forwards, to the anterior border near the base. The upper lobe, on each side, is smaller than the lower one, and resembles a cone having an oblique base; the lower lobe has a somewhat quadrilateral shape. The upper lobe of the right lung is subdivided by a second fissure, which, passing forwards and upwards from the oblique fissure to the anterior border, cuts off a small triangular lobe, named the *middle* or *third* lobe of that lung. A rudimentary third lobe is sometimes present in the left lung. In the right lung there are sometimes four lobes. The right lung is about an inch shorter than the left, and the concavity of its base is more pronounced: this corresponds with the higher position and greater convexity of the right half of the diaphragm, over the right lobe of the liver. The right lung is also wider than the left, the breadth of the latter being diminished by the projection of the heart into the left half of the thorax.

The root of each lung, which is found on the inner surface somewhat above the middle, and much nearer the posterior than the anterior border, contains, as already stated, the bronchus, the pulmonary artery, and the two pulmonary veins; it also includes the nutrient vessels or bronchial arteries and veins, lymphatics and lymphatic glands, nerves, and areolar tissue, all being surrounded by a tubular reflection of the pleura. In the root of the lung, the pulmonary artery is placed behind the pulmonary veins, but in front of the bronchus, bronchial vessels, and lymphatic glands. The relative position of the bronchus and artery from above downwards, differs on the two sides; on the right side, the bronchus lies above the artery; but on the left side, the bronchus (Fig. 111, 4), descending lower, to pass beneath the aortic arch, is placed below the artery, 6. The pulmonary veins, 7, 8, on both sides, are situated below the other structures.

The air-tube, bloodvessels, lymphatics, and nerves, found in the root of the lung, enter it, and, dividing and subdividing, penetrate not only its lobes, but reach certain much smaller portions of the lung substance, named the *lobules.* These lobules, which constitute the proper *pulmonary substance*, or *parenchyma*, are small compressed masses, which might be regarded as little independent lungs, or *lunglets;* they fit accurately against each other; they vary in shape and size, being, on the surface of the organ, large and pyramidal, with their base directed outwards, whilst in the interior, they are small and of irregular polyhedral shape. Each lobule is composed of a terminal branch of an air-tube, surrounded by a cluster of air-cells communicating with it; also of pulmonary and bronchial vessels, lymphatics, and nerves, with a fine interstitial areolar tissue. The lobules are supported on the terminal air-tubes, as if on stalks, but they are likewise held together by the vessels, and by an *interlobular* areolar tissue, which attaches their sides together, and is itself connected with a general covering of areolar tissue, found upon the surface of the lung, beneath the pleura, named the *subpleural* or *subserous* coat. Both the interlobular and subserous tissues contain many elastic fibres.

Fig. 111.

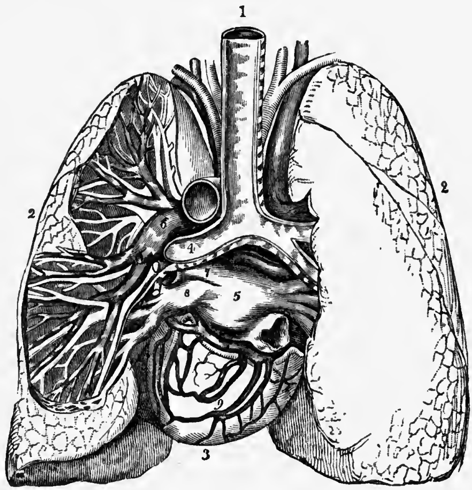


Fig. 111. Back view of the lungs and heart, with the air-tubes and great bloodvessels attached. 1, trachea or windpipe. 2, 2, lungs; the left one partly dissected, to show the bronchial tubes and the pulmonary arteries and veins branching in it. 3, heart. 4, left bronchus, entering at the root of the lung, beneath the arch of the aorta, which is seen cut across. 6, left pulmonary artery. 7, 8, left pulmonary veins, entering, 5, the left auricle; beneath the right pulmonary veins is the inferior vena cava, cut across. 9, back or under surface of the left ventricle of the heart.

On entering the lung, each bronchus divides into an upper and lower branch, one for each lobe; but, on the right side, the lower branch gives off a smaller one, which passes into the middle or third lobe of that lung. Inside the lung, the bronchi continue to subdivide, at obtuse angles, into smaller and smaller tubes, called *bronchia;* these never coalesce again, but continue separate, after the manner of the primary ducts of a gland, or of the branches of a tree. These tubes generally divide dichotomously, or in twos, but sometimes three bronchia proceed from a common trunk, or small lateral bronchia are given off. The finest bronchia, forming the *lobular bronchial tubes*, end in the lobules, as will presently be described. The combined sectional area of the smaller bronchia is very much greater than that of the larger bronchia or the trachea.

Within the lung, the bronchia are round, and not flattened posteriorly, like the trachea and its primary divisions in the root of the lung. Their constituent elements are similar to those of the trachea, but these are here much modified. Thus, the cartilages, instead of being arranged in regular transverse slips, assume the form of angular or polygonal plates of proportionate size, placed on all sides of the tubes. At the angles of bifurcation of the tubes, spur-shaped pieces of cartilage usually support them; minute flakes are found even in the smaller bronchia. But the cartilages are absent in bronchia the diameter of which is less than a quarter of a line; the walls of such tubes are entirely membranous. A fibrous coat and longitudinal elastic fibres are present in all the tubes, down to the very smallest. The muscular fibres of the unstriped kind, are no longer limited to the posterior portion of the tube, but, arranged in circular bundles, form a layer external to the cartilages; they extend to the smallest ramifications of the bronchia. The mucous membrane lining the bronchia is thinner than that of the bronchi and trachea, with which it is continuous; it is covered with a ciliated columnar epithelium. The walls of the bronchi and larger bronchia, are provided with mucous glands.

The terminal bronchial offsets distributed to the lobules, or the *lobular bronchial tubes*, divide within the lobules, from four to nine times, according to the size of the lobule. The branches thus formed become gradually smaller, being at length reduced to $\frac{1}{30}$th, $\frac{1}{50}$th, or $\frac{1}{70}$th of an inch in diameter. They finally terminate in the so-called *intercellular passages*, or *air-sacs*, which offer a marked contrast, both in form and structure, to the tubes; for instead of a cylindrical form, they appear like irregular passages, traversing the substance of the lobule at various angles, and communicating freely with each other; at the same time they no longer present either longitudinal, elastic, or circular muscular fibres. Moreover, the diameter of the intercellular passages is somewhat greater than that of the finest bronchial tubes from which they proceed, and it increases a little at each division, whilst the tubes, in this respect, as already mentioned, diminish in size as they divide. Finally, the sides of the intercellular passages, at first smooth, like those of the lobular bronchial tubes, soon become recessed by numerous closely-set, sharply-defined, cup-shaped depressions; these are the so-called *air-vesicles* or *air-cells*. An intercellular passage may, indeed, be regarded as a space between the air-cells, which surround it on all sides.

The *air-cells* or *air-vesicles* (Fig. 112, 2, 3), the ultimate recesses to which the minutely subdivided air gains access, measure from $\frac{1}{200}$th to $\frac{1}{70}$th of an inch in diameter. They are smaller in the interior of the lungs, larger on the surface, and largest at the apices and thin edges of those organs. They are larger in the male than in the female, and gradually increase in size as life advances. Those cells which occupy the central portions of a lobule, appear like polyhedral alveoli, separated from each other by delicate septa. By some, it is said that the sides of the cells are frequently perforated or deficient, so that neighboring cells com-

Fig. 112.

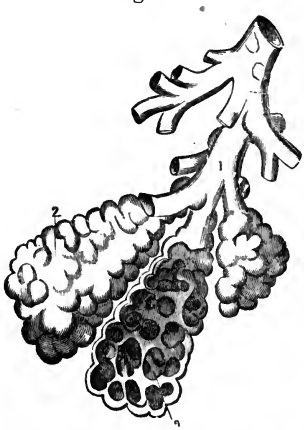


Fig. 112. Magnified diagrammatic view of groups or clusters of air-cells, one being laid open. 1, small bronchial tube, dividing into others which are membranous. 2, vesicular portion of lobule, with air-cells on its surface. 3, the same laid open, to show the recesses or air-cells in its interior.

municate with each other (Waters); but this is not universally admitted, at least as regards the human lung. The cells situated beneath the pleura, are four- or six-sided. No direct communication exists between the air-cells of adjacent lobules. The number of air-cells in both lungs has been calculated to be about 6,000,000. The walls of the air-cells are thin and transparent, and are composed of areolar, mixed with fine elastic tissue, lined by an exceedingly delicate mucous membrane, consisting of a thin transparent basement membrane, covered with a polygonal squamous non-ciliated epithelium.

The pulmonary arteries and veins are the functional, or respiratory, vessels of the lungs. The *pulmonary arteries*, unlike the systemic arteries, convey *venous* blood from the right ventricle of the heart to the lungs. The trunk of the pulmonary artery, having passed obliquely upwards and to the left, for about 2 inches, reaches the concavity of the aortic arch, and there divides into the right and left pulmonary arteries; each of these enters the corresponding lung, and divides into as many primary branches as there are lobes; these branches rapidly subdivide, in company with the bronchia, and finally end in the *pulmonary capillaries*. These last-named vessels, placed beneath the mucous membrane of the air-cells and intercellular passages, form a delicate and close network, composed of a single layer of small vessels, having exceedingly thin walls; their width varies from $\frac{1}{2400}$th to $\frac{1}{4000}$th of an inch; that of the meshes between them, is much less; at the sides of adjoining cells, the capillary network is placed between their adjacent walls, so that it is acted on by the air on both sides. The venules which arise from the capillary network, quickly join to form larger trunks, which generally pursue a different route to that of the arteries; they finally end in *four pulmonary veins*, two from each lung, which convey the *arterialized* blood to the left auricle of the heart. The pulmonary veins are destitute of valves; their capacity is said to be about equal to, or even less than, that of the pulmonary arteries. Within the lungs the pulmonary arteries are usually situated above the bronchial tubes, and the pulmonary veins below. The *bronchial* arteries are the nutritive vessels of the lung; they are given off from the aorta, or from an intercostal artery, and are distributed to the walls of the bronchia and pulmonary vessels, to the interlobular areolar tissue, and other neighboring parts; they usually end in the bronchial veins, but the branches which supply the smallest bronchia end in the pulmonary capillary network. The *lymphatics* are superficial and deep, and terminate in the bronchial glands at the root of the lung. The nerves are derived from the vagus and sympathetic; connected with the latter are numerous minute ganglia. (Remak.)

Fig. 113.

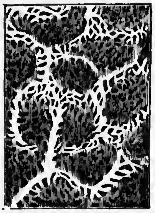


Fig. 113. Small portion of the inner surface of the air-cells, with the capillary network injected; the pulmonary capillaries are seen to be wider than the meshes between them.

Mechanism of Respiration.

The respiratory movements are of two kinds, viz.: those which draw air into the breathing organs, or the movements of *inspiration*, and those which expel the air from those organs, or the movements of *expiration*. A complete respiration therefore consists of an *inspiratory* and an *expiratory* act. Inspiration requires a greater effort than expiration. At the commencement of the independent existence of air-breathing animals, the former act precedes the latter, the lungs being then filled before air can be expired from them; on the other hand, the final respiratory act consists of an expiration, and to expire is synonymous with to die.

Inspiration.—The thorax is a closed cavity, with movable walls, the available space in which, beyond that occupied by the heart and blood-vessels, œsophagus, thoracic duct, lymphatic glands and nerves, is accurately filled by the two lungs. The interior of these spongy organs, however, communicates with the outward atmosphere, through the nose, mouth, pharynx, larynx, trachea, bronchi, and bronchial tubes. Hence any enlargement of the thoracic cavity from expansion of its walls, is immediately accompanied by the entrance of air, through the air-passages just mentioned, into the interior of the lungs, and by the inflation of those elastic organs, as they follow the expanding walls of the chest. In describing the inspiratory act, it is sometimes said that a virtual *vacuum* is formed in the thorax, which the air fills by entering through the only passages by which it can reach its interior. But the vacuum in question is only threatened or impending, none being really formed. The equilibrium between the atmospheric pressure on the surface of the lungs, acting through the walls of the thorax, and that on their interior, operating through the open air-passages, being disturbed by the active expansion of the thoracic parietes, through the agency of the inspiratory muscles, the air enters the air-passages simultaneously, in exact and instant correspondence with the amount of expansion, and the lungs as instantly become inflated, and follow the inner surface of the expanding thoracic walls.

In this inspiratory movement, the thorax is enlarged in each of its three dimensions: in depth from before backwards, in width from side to side, and in length or height from above downwards (see Fig. 114). The enlargement in *depth*, from the spine to the sternum, is accomplished by the elevation of the ribs, which being movably articulated with the vertebral column behind, and continued on, by their cartilages, to the sternum in front, and having, moreover, an oblique direction from their posterior to near their anterior extremities, necessarily cause an elevation and projection forwards of the sternum, when they are slightly lifted upon their posterior points of attachment, to a less oblique position. The point of support or fulcrum of each rib, is the vertebral column; whilst the connection of the upper ten ribs in front, directly or indirectly with the sternum, enables them to elevate and push forward that bone, and thus to increase the antero-posterior diameter of the chest. The enlargement of the thorax in *width* is likewise accomplished by the elevation of the curved and obliquely attached ribs; for by such a movement, as may be illustrated on the skeleton, or on an apparatus consisting of pieces of hoops attached obliquely to a common upright support, the ribs, in becoming more horizontal, are not merely lifted, but slightly rotated on their hinder attached extremities; their sides are thus carried outwards, their outer surfaces being turned somewhat upwards, and their inner surfaces downwards. The total result, as it affects all the ribs, is to expand the thorax in its transverse diameter. Lastly, the increase in the vertical diameter or *height* of the thorax, which, in its costal portion, is diminished by the antero-posterior and transverse expansion, is accomplished by the action of the arched or vaulted diaphragm, Fig. 114, *d*, which forms the base of the thorax. The central tendinous expansion, the diaphragm, is drawn down by the contraction of its circumferential muscular parts; and this movement, named the *descent of the diaphragm*, causes an important elongation of the thoracic space.

Fig. 114.

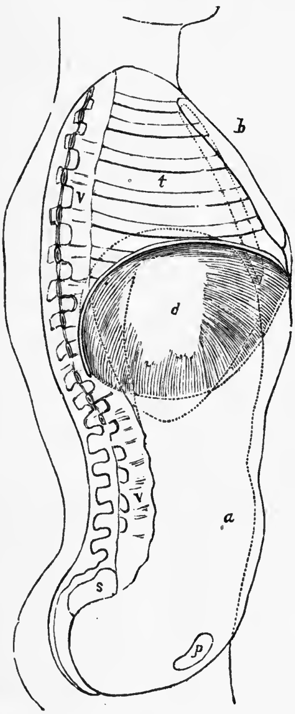


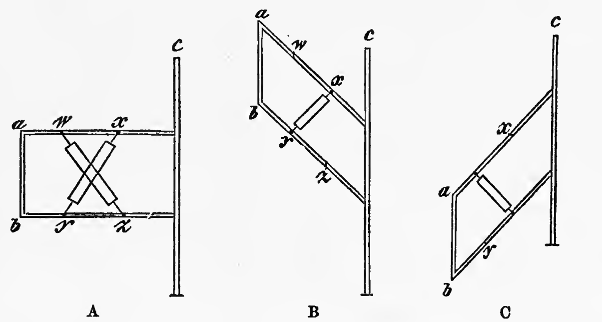
Fig. 114. Diagrammatic view of an antero-posterior section of the cavities of the thorax and abdomen, with the diaphragm intervening, to show the changes in the position of this septum, and of the walls of the chest and abdomen, in respiration; *a*, abdominal cavity; *t*, thorax; *v*, *v*, vertebral column; *d*, diaphragm. The dark lines show the position of the parts after inspiration, the dotted lines after expiration. *s*, section of the sacrum, and *p*, of the symphysis pubis, forming the posterior and anterior boundaries of the pelvic cavity, which communicates above with the abdomen.

Of these three modes of enlargement of the thoracic cavity, its elongation from above downwards, by the descent of the diaphragm, is by far the most considerable. In ordinary respiration, it constitutes in men, and, it is said, particularly in children, the principal respiratory movement; but it is accompanied by a slight lifting of the walls of the thorax, in front, at the sides, and especially at the lower part of the chest. When the diaphragm thus descends, the abdominal viscera do so likewise, and the abdominal walls, their muscles probably relaxing, become prominent; whilst in expiration, when, as may be supposed, the diaphragm ascends, the abdominal viscera are carried upwards, and the abdominal walls, slightly reacting, fall in. Hence, respiration performed, chiefly or entirely, by means of the diaphragm, is termed *abdominal*, *diaphragmatic*, or *inferior costal* respiration; it is the typical form of respiration in the male and in children. When breathing is mainly performed by the movements of the ribs, it is termed *pectoral* or *superior costal* respiration, and this is the characteristic form of breathing in the female, a fact which has been, by some, attributed to the habitual use of stays, but which may be a provision against the occasional impediment to abdominal respiration, which occurs in that sex. Over-distension of the abdomen, from any cause, as from gaseous or solid accumulations in the large intestine, tumors, or dropsical effusions, hinders abdominal respiration, the embarrassment to which is shown by the special efforts made to perform costal respiration. If the diaphragm contracted by itself, it would not only draw down its own tendinous vault, but would also pull the lower ribs downwards and backwards towards the vertebral column, and so diminish the lateral and antero-posterior dimensions of the lower part of the chest; but, in ordinary, and in deep inspiration, this tendency is counteracted by a proper adjustment of the force which raises the ribs.

The elevation of the ribs in inspiration is accomplished, in ordinary breathing, by the co-operation of a number of small muscles placed deeply between and upon the ribs. *First*, more especially concerned, are the *external intercostal* muscles. These occupy the interspaces between all the ribs, extending, in each intercostal space, from close to the vertebral column to the neighborhood of the costal cartilages; their fibres pass downwards and *forwards*, from one rib to another (see Fig. 4). It was at one time supposed that these muscles, being placed between adjacent ribs, could not elevate those bones, unless the uppermost rib was first fixed, but that then each intercostal muscle could raise the rib below it. It has been shown, however, by observations on living animals, that the action of these muscles in elevating the ribs, does not require the previous fixing of the first rib. The mechanical principle on which this apparently singular result depends, may be illustrated by a simple apparatus, consisting of an upright support of wood, to which two bars are so attached at one end, by means of pins, as to be capable of being elevated or depressed; the bars themselves being held horizontally, a piece of vulcanized India-rubber is fixed tensely, and obliquely downwards and forwards from the upright support, between the bars—*i. e.*, in the same direction as the fibres of the external intercostal muscles. When, now, the bars are drawn down, the India-rubber is stretched, and on being left free to act, immediately elevates both bars again, and supports them even in an oblique direction upwards. The explanation of this result is as follows: the elastic force tends to approximate the *ends* of the piece of vulcanized India-rubber; this can only be accomplished by such a motion of the movable bars as will bring the *points*, to which the ends of the India-rubber are fixed, as near together, *i. e.*, as nearly vertical to each other as possible; and this results in the joint elevation of both bars. In the living body, the vertebral column represents the upright support, and the ribs the bars; but the effect is here modified by the somewhat fixed condition of the cartilages of the ribs to the sternum, which bone is, accordingly, moved upwards and forwards. *Secondly*, there are found at the back of the chest, near the spine, and descending from the several dorsal vertebræ to the subjacent ribs, muscles known as the long and short *levators of the ribs*. These not only assist in elevating the hinder parts of the ribs, but also slightly rotate them, so as to evert their lower borders. This slight rotation of the ribs, which accompanies their elevation, increases the diameter of the chest, and also widens each intercostal space along the sides of the thorax, where the ribs are more movable than at their anterior and posterior extremities. The elasticity of the costal cartilages is highly favorable to this elevation and rotation of the ribs, rendering both movements easier of execution than if the costal framework were entirely composed of bone. *Thirdly*, besides the simpler action of the levators of the ribs, and the more complex movements of the external intercostals, it is certain that a portion of the so-called *internal intercostals* may, as will again be mentioned, also aid in elevating these bones and the sternum.

[The action of these muscles may be rendered plain by a reference to the accompanying drawing, from Prof. Huxley's *Lessons in Elementary Physiology*, remembering that when a muscle contracts, it tends to make the distance between its two ends as short as possible. Let *a* and *b* in the figure represent two parallel bars, movable

Diagram L.



[Diagram of models illustrating the action of the external and internal intercostal muscles. B, inspiratory elevation; C, expiratory depression. (From Huxley's *Lessons in Elementary Physiology*, page 89.)]

by their ends upon the upright *c*, which may be regarded as the back of the apparatus; then a line directed from *x* to *y* will be inclined downwards and forwards, and one from *w* to *z* will be directed downwards and backwards. It is obvious that there can be but one position of the rods in which the points *x* and *y* are at their shortest possible distance, and one position only in which the points *w* and *z* are at the shortest possible distance; and these points are, for *x* and *y*, the position B, and for *w* and *z* the position C. These positions are respectively such that the points *x*, *y*, and *w*, *z*, are at the ends of a straight line perpendicular to both rods, for the shortest distance between any two points is always in a line perpendicular to the two points. And to bring *x* and *y* into this position, the parallel rods in A must move upwards; and to bring *w* and *z* into it, they must move in the opposite way. And it is thus proved that the external intercostals raise, and the internal intercostals depress the bony ribs.

F. G. S.]

In deep inspiration, many more muscles come into play than in ordinary breathing. Thus, the anterior and posterior *scaleni* muscles, which descend, on each side, from the cervical vertebræ to the first and second ribs, aid powerfully in elevating those ribs, and, through them, perhaps all the others. The *posterior superior serrati* muscles, situated deeply, one on each side of the back of the chest, must also raise certain of the ribs. The *cervicales ascendentes* muscles will have a similar action. If the scapula, or shoulder bone, and the clavicle, or collar bone, are previously fixed by the muscles which descend to them from the head and neck, viz., by the *trapezius* (Fig. 5, 2), *sterno-mastoid*, *levator* of the angle of the *scapula*, and greater and lesser *rhomboid* muscles on either side, then a very large and important muscle, the *great serratus* (Fig. 4, 5), which passes from the base of each scapula, over the sides of the chest, to the eight upper ribs, must also assist powerfully in expanding the chest, by raising and drawing the ribs outwards. So, likewise, in front of the thorax, the *subclavius* muscle, which passes from the collar-bone to the first rib, and the *lesser pectoral* muscle, which descends from the scapula to the third, fourth, and fifth ribs, on each side, will then serve to elevate the ribs. In still more forced inspiration, when even the arms are fixed, by holding on to some external object of support, the *great pectoral* muscles in front (Fig. 4, 2), and the *latissimi dorsi* behind (Fig. 5, 3), both of which, besides other attachments, are connected, on the one hand, with the humerus, and, on the other, with certain of the ribs, may then co-operate in the elevation and outward rotation of these latter bones, and thus assist in inspiration. All the muscles just mentioned, are named *auxiliary muscles* of inspiration; but a few of them only, those first described, are ordinarily employed in deep inspiration. In very extreme cases, however, nearly every muscle of the body may assist in inspiration, by fixing certain parts, and thus affording more efficient points of action to the proper respiratory muscles.

The chief work performed in the act of inspiration, consist in overcoming the elastic resistance of the costal cartilages, and lifting the weight of the ribs. The lungs themselves are passive, or rather their elasticity has to be overcome. These organs, becoming inflated in every direction from their roots, as they follow the thoracic walls, are necessarily enlarged in all directions, antero-posteriorly, transversely, and vertically. The elastic fibres of the air-tubes yield both in a longitudinal and a circular direction. The elastic walls of the air-cells are extended generally; so also are the interlobular and sub-serous areolar tissue, and the pulmonary and costal pleuræ. To facilitate the ingress of air, the air-passages, from the nose and mouth down to the interior of the lungs, are supported either by bones or cartilages, as, for example, by the cartilaginous alæ of the nostrils, the bones of the nasal cavities, the cartilages of the larynx, the incomplete cartilaginous hoops of the trachea and primary bronchi, and lastly, by the less regular, but well-adapted plates of cartilage of the secondary bronchi and the bronchia. As especially fitted to maintain the perviousness of the bronchia, the cartilaginous spurs placed at the angles of bifurcation of those tubes, deserve particular mention.

Through simple membranous tubes, however firm, the free and instant entrance of the air necessary to proper inspiration, would have been impracticable; and, moreover, such tubes would have quickly collapsed during expiration. At the larynx, the narrow triangular glottis has musculo-membranous margins; but the state of this aperture is regulated by the nervous system, which exercises a special control over it, and though it may be voluntarily or involuntarily closed, it is habitually open.

Mechanical obstructions in any part of the air-passages, by excluding the air, may prove fatal. The forcible closure of the mouth and nose for criminal purposes, the wilful filling of the fauces with a handkerchief or cloth, the compression of the windpipe, the accidental impaction of pieces of food or of some foreign body in the glottis, closure of this aperture from spasm, or from swelling of the surrounding mucous membrane, a condition known as œdema of the glottis, the lodgment of masses of food, too large to be swallowed, in the œsophagus, and, lastly, the introduction of fluid in any quantity, as in drowning, operate in this way.

When the thoracic walls are so injured that an opening exists through them into the pleural chamber, their expansion is no longer followed by the proper inflation of the lungs; but the air passing in through the artificial opening, to supply the threatened vacuum, the lung is subjected to equal atmospheric pressure both on its pleural surface and within its air-passages and air-cells, and owing to the elasticity of its component structures, it collapses to a greater or less extent. If the opening be oblique or valved, as in certain punctured or gunshot wounds, some air may still enter the lung by the trachea. As the two pleuræ form distinct chambers, when one only is punctured, the corresponding lung alone becomes collapsed, and though respiration is embarrassed, death does not necessarily ensue. If, however, both pleuræ are simultaneously wounded, both lungs collapse, and death follows from asphyxia or suffocation.

Expiration.—The movement by which the air, having entered the lungs by an inspiratory effort, is again driven from them, is more passive in its character than that of the inspiration, depending less upon muscular action, but more on the relaxation of the inspiratory muscles, and on the elastic resilience of the organs and tissues concerned.

As the muscles of inspiration cease to act, the tendinous part of the diaphragm, the chief of those muscles, ascends into the thorax, followed by the abdominal viscera, which are supported in their upward movement by the co-operation of the muscles of the abdominal walls. At the same time the ribs and the sternum, which were elevated, descend and fall back, whilst the effects of the rotation of the ribs are counteracted by the elastic recoil of the costal cartilages. Lastly, the elasticity of the lungs themselves plays a most important part, acting like an extended spring let loose, and serving to expel the air from the air-tubes and air-cells. The longitudinal and circular fibres of the bronchi and bronchia shorten and narrow those tubes; the elastic walls of the air-cells diminish their size, and the interlobular, and especially the subpleural elastic tissues, aid powerfully in compressing every portion of the lung.

The importance of the elasticity of the component structures of the lungs, as an expiratory force, is shown by an experiment, which also illustrates the mode in which a lung expands by the removal of atmospheric pressure from its outer surface, and by the concurrent entrance of air, under its ordinary pressure, into the bronchial tubes. A bell-shaped glass jar, having a wide mouth below, and a strong open neck at its upper end, has the latter opening fitted with a perforated cork, tightly cemented in. The lower end of a glass tube, about $\frac{1}{2}$ inch wide and 1 foot long, is closely secured into the bronchus of a sheep's lung; the upper end of this tube is then passed up into the bell-shaped glass jar, and pushed through the hole in the cork, until the lung is suspended high up in the jar; the tube is then hermetically cemented to the orifice in the cork, its upper end being left free and open. A piece of moistened bladder, in the centre of which a stop-cock is closely tied, so as to project outwards, is now placed loosely over the mouth of the jar, and is tightly secured to its rim by cord. When the apparatus is held upright, the glass-tube represents the trachea, and the bell-shaped jar may be compared to the thorax, with this difference, however, that its sides are not movable, and are not in contact with the lungs; lastly, the loosely extended moist sheet of bladder occupies the position of the diaphragm, the upward vaulted form of which may now be imitated by opening the stop-cock in the centre of the bladder, thrusting this latter up into the bell-jar, and then closing the stop-cock. In this position the bladder is supported by the atmospheric pressure, and the suspended lung is quiescent. On now pulling the stop-cock downwards, the bladder descends, imitating the descent of the diaphragm, the atmospheric pressure on the surface of the suspended lung is removed, and, in anticipation of the threatened vacuum, air enters, through the glass-tube, into the interior of the lung, which, as may be seen through the jar, immediately becomes inflated. In this condition the elastic tissues of the lung are put upon the stretch. But if the stop-cock be let go, the elastic resilience of this organ causes the lung once more to contract, and the artificial diaphragm of moist bladder again ascends into the jar, until the atmospheric equilibrium, inside and outside the lung, is re-established. The experiment may be repeated, again and again, the accidental entrance of an excess of air between the sides of the jar and the surface of the lung, being remedied by opening the stop-cock, thrusting the bladder well up into the jar, and then closing it again. If desired, a manometer may be adapted by a separate opening to the top of the jar, so as to measure the expanding force used in distending the lung, as the bladder is drawn down. The two lungs of a dog, connected with the trachea, answer for this experiment as well as the sheep's lung; but the elasticity of the lung of the seal or the lion, is much greater. The elastic force of the human lung has been calculated at 8 oz. per square inch of surface, being equal to about 150 lbs. in the male, and about 124 lbs. in the female. (Hutchinson.)

It has been shown experimentally, that the contractility of the unstriped muscular fibres of the air-tubes is excited by electricity, as well as by chemical and mechanical stimuli; and it has been suggested that they may assist in expelling air from the lungs; but the slow action of organic muscular fibres, renders it unlikely that they co-operate in movements so rapid as those of respiration; it is more probable that they regulate the diameter of the air-tubes, and perhaps aid in expelling mucus or other secretions from the smaller tubes. The cilia, which exist throughout the air-tubes, from the entrance of the air-cells upwards beyond the larynx, not only assist in the diffusion of moisture over the interior of these tubes, but perhaps also in retaining particles of dust which abound in the air, and so preventing their reaching the air-cells, and likewise in impelling upwards towards the glottis, mucus, and entangled particles of matter. The current produced by these cilia, always sets in the upward direction.

Ordinary expiration is undoubtedly aided by certain proper expiratory muscles, especially by the *internal intercostals.* These muscles occupy only the anterior three-fourths of the intercostal spaces, being absent at the back part of the chest; they are placed inside the external intercostals. Their fibres pass, in each space, from above, downwards, and *backwards*, or in the opposite direction to the fibres of the external intercostals. As already alluded to, the forepart of these muscles near the sternum, especially of the four or five upper ones, is said to assist in elevating the ribs in inspiration; but, elsewhere, these muscles depress the ribs, invert their lower edges, and diminish the width of the intercostal spaces, thus acting as expiratory muscles, diminishing the capacity of the thorax, both from before backwards, and in width. Within the internal intercostals are situated the *infracostals*, small muscular bundles, having the same direction as the internal intercostals, but reaching over two or three spaces; they are also expiratory muscles. The *triangulares sterni*, small thin muscles, found on the internal surface of the sternum and cartilages of the true ribs, likewise co-operate in expiration; some maintain, however, that a portion of these muscles is inspiratory. The *auxiliary muscles of expiration*, are the upper part of the *serratus magnus*, when the scapula is previously fixed; the *posterior inferior serrati*, which pass from certain dorsal and lumbar vertebræ upwards to the last four ribs; the *quadrati lumborum* muscles, which ascend from the pelvis and lumbar vertebræ to the lower ribs; certain portions of the long muscles of the back, known as the *erectores spinæ;* and, lastly, the abdominal muscles which are concerned in drawing the lower ribs downwards and inwards, such as the *external* and *internal obliqui*, the *transversales*, the *recti*, and *pyramidales* muscles. The abdominal muscles assist, even in ordinary expiration, by supporting or raising upwards and backwards the abdominal viscera, when the relaxation of the diaphragm causes these to ascend. In extremely forcible expiration, as in powerful inspiration, all the muscles of the body may be brought into some action. It is remarkable that a single small muscle, the *arytenoid* (p. 207), which closes the aperture of the glottis, may, by an act of the will, be made to counteract the powerful efforts of the ordinary and auxiliary muscles of expiration. Under this condition, the walls of the thorax are rendered tense and firm, so as to form a solid base of support for the forcible use of the upper limbs. So also in voluntary or involuntary abdominal expulsive efforts, the chest is usually first filled by an inspiratory act, in which the diaphragm descends, and then, the glottis being closed, the diaphragm is fixed, and the abdominal and auxiliary expiratory muscles come into action, so as to compress the abdominal contents.

The movements of inspiration and expiration which constitute a complete respiratory act, succeed each other alternately, from the moment of birth until that of death; and this character of succession is named the *rhythm* of the respiratory acts.

The *number* of complete respirations in a given time varies according to many conditions. In the adult, the respirations vary from 14 to 18 per minute; in childhood, at about five years of age, they are said to be about 26 per minute; whilst at birth, they are as many as 40 to 50; in extreme age, the frequency of the respirations is again increased. Persons of small stature breathe more quickly, but less deeply than taller people. The respirations are less frequent, but deeper in the male than in the female. The number of respirations is increased by exercise and work, by food, stimulants, and moderate cold, and at great altitudes; whilst it is diminished in sleep, by moderate heat, by increased barometric pressure (see p. 656), by starvation, and by depressing influences and agents generally. It is curious that if the attention be directed to the breathing, the number of respiratory acts is usually diminished. In quick walking, the respirations may be 30 in a minute; in running, 70; and in violent efforts, as many as 100 per minute. In sleep, the respirations are slow, because the interval between expiration and inspiration is unusually prolonged. As elsewhere noticed, there is a certain ratio, in health, between the number of the respirations and that of the beats of the heart, the proportion between them being in the adult, usually about 1 to 4. In childhood, the respirations are relatively quicker, their proportion to the pulse being from 1 to 3 or 3½. The ordinary ratio between the respirations and the pulse is maintained in the daily and seasonal variations of the latter. But in certain diseases it is seriously disturbed, and forms an important guide in medical practice; thus in pneumonia or inflammation of the lungs, the respirations are so quickened, through embarrassed function, from congestion of the vessels, that the ratio may even be as 1 to 2. In hysteria, the respirations are also much increased in proportion to the pulse. In typhoid states, and in narcotic poisoning, the respirations become so slow, owing to some influence on the nervous centres, that their ratio to the pulse may be as 1 to 8.

The whole period occupied by a complete respiration, is divisible into three *stages*—viz., an inspiratory and an expiratory stage, followed by a *pause*, or stage of rest. According to some, there is also a pause between inspiration and expiration, but this can very seldom be recognized or measured. The total period of a respiration, being represented by 10, the inspiratory movement occupies 5 parts, the expiratory 4, and the recognizable pause between this and the succeeding respiratory act, 1. The period of motion to that of rest, is therefore as 9 to 1. (Walshe.) According to Vierordt, the period of inspiration being equal to 10, that of expiration, together with the pause, is, in deep respirations, 14; in quick breathing, 24. As he estimates the pause at one-fifth of the whole period, the numbers representing the inspiration, the expiration, and the pause, would, in the former case, be 10, 9, and 5, and in the latter 10, 17, and 7. According to recent observations with the sphygmograph and kymographion, the whole respiration period being 15, inspiration occupies 4, expiration 2, and the pause 9 parts; the ratio of the movement to the pause is as 2 to 3. (Sanderson.) In the disease called emphysema, which consists in a dilatation of the air-cells, the periods of expiration and inspiration are equal, or the former is even longer than the latter. In cases of tubercular deposit, the expiration is also prolonged.

The force exercised by the inspiratory muscles in ordinary respiration, in an adult man, varies from about 1.5 inch to 4.5 inches of mercury; but, in exceptional cases, it may rise to even 7 inches. This force increases more rapidly than the actual amount of expansion of the chest, for when, in the same body, 70, 90, 190, and 200 cubic inches of air were injected into the lungs, the pressure was found to be 1, 1.5, 3.25, and 4.5 inches of mercury. The expiratory force is, on an average, about one-third or one-fourth stronger than the inspiratory force, varying from 2 to 5.8 inches of mercury, and rising even, in certain cases, to 10 inches. (Hutchinson.) This is due to the co-operation of the elasticity of the lungs, and the resilience of the chest-walls, with the muscular effort. The force of the inspiration is, therefore, the severer test of the strength of the body. The expiratory power is said to be greater in men of 5 feet 7 or 5 feet 8 inches in height, than in those either above or below that stature.

The entrance and escape of the air into, and out of, the air-tubes and air-cells, during inspiration and expiration, produce certain sounds named *respiratory murmurs*, which may be heard by the ear placed on the chest or by aid of the stethoscope. In health, the inspiratory and expiratory murmurs, named the bronchial or *tubular* sounds, which depend on the movement of the air through the air-tubes, are heard over the site of the larger bronchia, between the scapulæ, and over and near the upper part of the sternum. They are distinct, and characterized by a soft blowing noise; those of inspiration and expiration are of nearly equal duration. The *vesicular* respiratory murmurs, dependent upon the entrance and escape of the air in, and out of, the air-cells, are only faintly audible, like a gentle breezy noise; the expiratory vesicular murmur is weaker, and three or four times shorter, than the inspiratory murmur. The duration of the sounds is altered by the same causes as those which modify the length of the movements of inspiration and expiration.

Accumulations of mucus or other secretions in the air-tubes, produce abnormal sounds, which are named *rhonchi*, or *rales*. These vary in character, according to the seat, quantity, and nature of the secreted matters. Thus, a fine *crepitant* rhonchus is produced by fluid exudations in the air-cells, in pneumonia; a *subcrepitant* rhonchus arises from the bubbling of air through fluid in the smaller air-tubes; a *sonorous* rhonchus, with its snoring, rasping, and cooing varieties, depends on obstructions in the larger air-tubes; a *sibilant*, or *whistling*, rhonchus is caused by mucous accumulations in the air-passages; and, lastly, a *cavernous* rhonchus is produced in cavities, or caverns, in the lung, formed in the destructive stage of phthisis. Peculiar, harsh, rubbing, or grating noises, named *friction-sounds*, frequently heard in inflammation of the pleura, are caused by the rubbing of rough exudations of lymph effused on the pulmonary or costal pleura. Again, the relative amount of air and tissue in different parts of the thorax, causes differences in the sounds produced by *percussion* with the fingers, or otherwise, at different points of the thoracic surface. The percussion-sound over the lungs is more hollow, or, as it is termed, *resonant*, than over the heart, or great bloodvessels; the ascent of the convex liver into the concave base of the right lung, the two being of course separated by the diaphragm, alters the percussion-sound, by diminishing the resonance at the base of the right side of the chest. The chest is more resonant over the great bronchi, than at other parts of the lungs. The resonance is everywhere greater in thin persons. Various changes in the lungs produce great alterations in the resonance of the corresponding parts of the chest; congestions, thickenings, consolidations, accumulations of fluid as in hydro- or hæmothorax, or empyema, and the presence of tumors, cause dulness in the percussion-sounds; whilst an abnormal amount of air, either in dilated or ruptured air-cells, as in emphysema, or the cavities excavated in the lung-substance, as in phthisis, or in the pleural chamber, as in pneumothorax, cause an increased degree of resonance on percussion. Lastly, the term *vocal resonance* is applied to the sound heard on the surface of the chest whilst the person is speaking; it is also modified by various internal conditions. A vibration felt on the walls of the chest, during speaking, is called the *vocal fremitus*.

The *rhythmic* movements of respiration are governed by a special part of the nervous centres, co-operating with certain nerves. The rhythmic movements of the heart, not yet fully explained, are performed by a muscular organ, itself entirely uninfluenced by the will. But the muscles of respiration are truly subject to the will. We can increase or diminish the rapidity and force of these movements, according to our pleasure; we may imitate them, and can interrupt or arrest them at any chosen point of the respiratory act. This latter power is, however, of limited duration. Very prolonged interruption of the respiration produces convulsions. But, even after a period of from twenty to thirty seconds, there arises, when the breath is held, a feeling so distressing that it overcomes the most powerful volition. This feeling, termed *want of breath*, at last irresistibly compels the resumption of the respiratory acts. Like other sensations, it has its seat in some portion of the gray substance of the nervous centres, and these being irritated excite the motor nerves of the muscles of inspiration, which are then thrown into involuntary action. The ordinary respiratory movements are also involuntary; they continue to be regularly performed during the profoundest sleep, in a state of coma, in deformed infants in which the cerebrum is deficient, and, for a time, even in animals after the head has been removed. The respiratory movements are, indeed, the most striking examples of reflex movements in the body. Their nature has already been generally discussed (p. 274). The afferent or excitor nerves of inspiration are the pulmonary branches of the pneumogastric and sympathetic nerves, which latter contain fibres derived from the spinal cord; also the cutaneous nerves of the face belonging to the fifth cranial pair, and the cutaneous nerves of the body generally. The nasal nerves and the laryngeal branches of the pneumogastric, excite expiratory movements, as in sneezing and coughing. The nervous centre which governs the respiratory movements, is a limited portion of the gray matter of the medulla oblongata opposite the roots of the pneumogastric nerves, as has been proved experimentally (p. 281). The so-called *vital knot*, at the back of the medulla, corresponds with the interval between the occipital bone and the arch of the axis; in this space an animal may be suddenly killed by introducing a sharp, strong knife, so as to *pith* it, or divide the medulla. The efferent or motor respiratory nerves are: the phrenic nerves, which supply the diaphragm; the intercostal nerves, which supply, amongst others, the muscles of that name; the *long thoracic*, or so-called *external respiratory nerves* of Bell, which are distributed to the serrati muscles; the *spinal accessory* nerves, which supply the trapezii muscles; and the *facial* nerves. In extreme respiratory efforts, other motor nerves are of course concerned. The reflected stimulus is conveyed to the roots of these nerves, along a particular tract of the spinal cord, situated behind the anterior roots of the spinal nerves, and descending along the lateral columns of the cord, from between the olivary and restiform bodies; this is the *respiratory tract* of Sir C. Bell, but, except as a path of special conduction, it has no respiratory influence. It is remarkable that the phrenic nerves, which supply the diaphragm, the most active muscle in inspiration, arise from the cervical plexus, and therefore form a part of the cord much higher than the roots of the highest intercostal nerves. Hence it happens that in certain injuries or diseases of the spinal cord, when the seat of these is above the origins of the intercostal, but below those of the phrenic nerves, costal respiration may be entirely abolished, whilst diaphragmatic breathing goes on. In such cases, however, death ultimately occurs from asphyxia, caused by the slow exudation of fluid into the lungs.

The respiratory movements being regarded as reflex or excito-motor, the first act of inspiration performed at birth, is said to be induced by the stimulus of cold acting on the excitable extremities of the fifth cranial nerves, which supply the nasal fossæ and the skin of the face, and also on those of the cutaneous nerves of the whole body. Cold, or a smart blow applied to the surface of the body of an apparently still-born infant, will sometimes excite inspiration; and, moreover, if the face of an infant be protected by warm covering, the first inspiratory act may be postponed. (Marshall Hall.) Once established, the reflex respiratory movements are believed to be excited by a peculiar stimulus, accompanying the sum of disagreeable sensations included in the feeling of want of breath. By some, it is supposed that the venous blood, deprived of oxygen, and loaded with carbonic acid gas and other effete matters, owing to the periodic interruption to the process of oxygenation, may be the cause of some of those disagreeable feelings, and may periodically stimulate the medulla and spinal cord, and so rhythmically excite the motor nerves of inspiration; according to others, it is rather the want of oxygen, which excites the movements, for an excess of that element enfeebles them.

The division of one vagus nerve in an animal, as a rule, lowers the frequency of, and embarrasses, the respiration, and the lungs become sometimes, but not always, the seat of extravasations of blood. Division of both vagi nerves in the neck immediately diminishes the frequency of the respirations to one-half, and later to one-third, or even one-fourth, of the normal number; the inspirations become not only slower, but deeper, embarrassed, and puffing, or spasmodic; the expirations, on the other hand, are shorter; whilst the pause between the expiration and the succeeding inspiration becomes more and more prolonged, which accounts for the diminished number of respiratory acts in a given time. Death usually takes place after from two to six days; the blood first becomes darker, as indicated by blueness of the lips, the temperature sinks, and the animal dies of asphyxia. Congestion of the pulmonary vessels, extravasations of blood, and exudations of frothy sanguineous serum and mucus, are found in the air-cells and bronchial tubes, and partial solidification of the lung-tissue occurs. Sometimes, however, death appears to ensue from disturbance of the digestive functions; but if these be recovered from, the animals may then live for many days. The continuance of the respiratory movements, for a time, after division of the pneumogastric nerves, depends on the excitability of the other afferent nerves of the body, especially of those of the skin. It seems doubtful whether the unstriped muscular fibres of the bronchial tubes can be excited through the pneumogastric nerves. Their contractility is soon exhausted by stimuli directly applied to them; moreover, it is lessened by certain narcotics, especially by belladonna and stramonium; hence the use of such remedies in asthma, in relieving the paroxysms of dyspnœa, which are supposed to be due to a spasmodic contraction of these organic muscular fibres.

The respiratory apparatus is employed, either voluntarily or involuntarily, in many other acts necessary to the economy, or conducive to its comfort. In these, the movements of respiration are sometimes accelerated or strengthened, and sometimes diminished or checked.

Thus, *speaking*, *singing*, *shouting*, and *whistling*, are volitional movements, requiring special voluntary efforts of expiration, often modified and graduated in the most varied yet exact manner, and supported by inspirations performed at stated and suitable times. The act of *spitting* consists of a sudden expiration accompanied by a peculiar position of the tongue, lips, teeth, and cheeks, having for its object the expulsion of saliva or other accumulations from the mouth.

The semi-voluntary or involuntary acts which necessitate the co-operation of the respiratory apparatus, are much more varied. Thus, *coughing* is a sudden, strong expiration, accompanied by a peculiar noise, following a closure of the glottis and of the upper opening of the larynx, and usually preceded by a deep inspiration, to give effect to the cough. A column of air, suddenly driven from the air-tubes, as suddenly opens the glottis, and, being forced through the mouth, moves on accumulations or foreign bodies, and expels them from the bronchi, trachea, and larynx. *Sneezing* consists of a quick, noisy expiration, following a decided, sudden, and deep inspiration; but the glottis is not closed, as in coughing, and the column of air is not driven through the mouth, but is directed, by the closure of the fauces, into and through the nasal fossæ. The irritation which causes sneezing, has its seat in those fossæ, whilst that which induces coughing, as is well known, resides in the fauces, the larynx, especially at the glottis, or in the air-tubes. The stimuli which excite coughing are cold air, irritating gases, fluids or solids, and diseased secretions. The noise of sneezing is produced in the nose; whilst that of coughing originates at the glottis. *Snoring* is produced by the resonance of the air passing, in or out, through the nasal cavities and the throat, owing to some irregular vibrations of the soft palate and uvula; it is sometimes dependent on narrowing of the fauces by enlargement of the tonsils, or on other peculiarities of conformation. In snoring, there is no special modification of the respiratory movements themselves, either as to force, frequency, or quickness. *Yawning* consists of a deep prolonged inspiration, the air being drawn in through the mouth, which is widely opened, by a consentaneous spasmodic action of the muscles of the lower jaw; this is then followed by a slow expiration, accompanied usually by a lifting of the soft palate, and sometimes by a prolonged characteristic sound. It may be accomplished by the will, and is often the result of involuntary imitation. *Sighing* also consists of a slow, deep inspiration, mostly accomplished through the mouth, and followed by a prolonged expiration, likewise associated with a peculiar sound; it often occurs after the attention has been strongly fixed; it is usually emotional. *Sobbing* is produced by rapid convulsive contractions of the diaphragm, associated with closure of the glottis. In *crying*, the movements resemble those of laughter, to be next described, although they are excited by very different emotions. *Laughing* consists of a series of sudden, short expirations, quickly succeeding each other, and divided, as it were, by intermediate closures of the glottis, giving rise to peculiar interrupted sounds. Laughter furnishes an excellent example of a reflex respiratory movement, excited either by sensori-motor impressions acting through certain cutaneous nerves, as when it is caused by tickling, or by emotional stimuli, as when it is the result of joy, or by a volitional stimulus, as when it is imitated by the actor. Lastly, *hiccup* is a short, sudden inspiration, produced by a sharp, convulsive contraction of the diaphragm, at the end of which the glottis is suddenly and spasmodically closed, so that the air strikes it from below. Of these varied movements, some, such as sighing and yawning, may be induced by certain conditions of the respiratory organs themselves, whilst others, such as laughing and crying, are never so excited.

Movement of the Air in Respiration, and Capacity of the Lungs.—After the lungs have been once inflated, as in the newborn infant, they are never, except from disease, entirely emptied of air. The most forcible expiration fails to accomplish this, and the quantity of air then retained in their tissue is termed the *residual* air. The quantity above this, held in the lungs after an ordinary expiration, but which may be expelled by a voluntary forced expiration, is called the *reserve* air, or sometimes the *supplemental* air. The quantity inspired and expired at each ordinary respiratory act is called the *breathing* or *tidal* air; and the still further quantity, which can be drawn in by a forcible inspiration, is termed the *complemental* air. (Julius Jeffreys.) The total quantity which, after the deepest inspiration, can be expelled by the fullest expiration, is considered the measure of the so-called *vital capacity* of the chest or of the individual, because it shows the volume of air which is commanded by the vital movements of the thoracic walls. It is the extreme *differential capacity* of the chest, minus the space occupied by the residual air, which cannot be expelled; it represents the total difference between the fullest inspiration and the fullest expiration. This vital capacity in any individual is of great importance as indicating the extreme power of breathing in exercise or effort; and it furnishes highly significant information in certain diseases, especially in those of the lungs themselves. (Hutchinson.)

The determination of the actual quantities of air which are the measures of the residual, reserve, breathing, and complemental air, and that of the total respiratory power or vital capacity of the chest, is extremely difficult. The elaborate and successful researches of Hutchinson were made by means of his so-called *spirometer*. This apparatus is really a miniature gasometer; it consists of an inner cylinder, closed at its upper end, but open below, where it dips into water contained in an outer larger cylinder, which is closed below and open above; and it has a scale by which its ascent and descent can be measured. The inner cylinder is accurately balanced by weights attached to cords passing over pulleys affixed to the outer cylinder. The inner cylinder being depressed, and allowed to fill with water, the person experimented on blows air into it by a tube which passes beneath its open mouth. The cylinder is raised, and when the expiratory effort is complete, the tube is closed by a stop-cock, so as to retain the air in the spirometer, and its quantity is read off upon the scale.

The *residual* air has been variously estimated at from 40 to 260 cubic inches; but, according to Hutchinson, it ranges from 75 to 100 cubic inches. It is most difficult to measure; for, after death, the lungs are not so empty of air, as they are after forced expiration during life, and it is not easy to estimate the difference. Besides, although the amount of residual air corresponds generally with the size of the chest, it is influenced also by the relative mobility or stiffness of the walls, so that age, imparting rigidity to the costal cartilages, increases the residual, at the expense of the reserve or supplemental air. The residual and reserve air together are taken, in the adult male, to be from 150 to 200 cubic inches. (Hutchinson.)

Accurate estimates of the so-called breathing air and vital capacity, are of great importance. The *breathing air* has been differently calculated, from 10 to 92 cubic inches; but, according to the most recent observers, it ranges, in the adult male, from 16 to 20 cubic inches (Hutchinson), from 17 to 33 (Vierordt), from 16 to 25 (Coathupe), and from 30 to 39 cubic inches, in persons whose stature varies from 5 feet 7½ inches to 6 feet. (Dr. E. Smith.) A fair estimate for a person of mean height, 5 feet 6½ inches, would be about 20 cubic inches, for the average of the *day* and *night* respirations. The *vital capacity* in an adult male, of the stature of 5 feet 7 inches is, on an average, about 230 cubic inches, the air being supposed to be at a temperature of 60°. The *complemental* air would therefore be 120 cubic inches.

The following are the estimated quantities, in cubic inches, calculated for the daily and nightly average, in a man of the stature of 5 feet 6½ inches:

	Cubic Inches.	
Residual Air, ...	90	
Reserve Air, ...	90	Total displaceable Air, or Vital Capacity = 230 cubic inches.
Breathing Air, ...	20	
Complemental Air, ...	120	
Total Air after deepest Inspiration,	320	

These numbers cannot be regarded as absolutely accurate, but they illustrate the general proportions. The depth of an ordinary inspiration, as measured by the breathing air, and the total displacement of air in forced respirations, indicating the vital capacity, differ much, according to the size of the body, but even in persons of the same age, height, and weight, they are liable to variation; for they do not merely depend on the size of the thorax, but necessarily on the *mobility* of its walls, and on the extent to which they are actually moved in the several inspiratory and expiratory acts. This may partly account for the great diversity in the estimates of the breathing air. The vital capacity has been shown to differ according to the *stature;* the variation in persons between the heights of 5 and 6 feet, follows a sort of law, every additional inch of height being accompanied by an average increase of 8 cubic inches in the vital capacity. Thus the capacity at 5 feet 6½ inches being 230 cubic inches, that at 5 feet would be about 174, whilst that at 6 feet would be about 270 cubic inches. The vital capacity in women is much smaller than in men, the proportion being almost as 1 to 2. It increases, in both sexes, from 15 to 35 years of age, at the rate of about 5 cubic inches per annum; whilst from 35 to 65, it diminishes by 1½ cubic inch in a like period. The greatest capacity met with by Hutchinson, was in a giant 7 feet high, who weighed 308 lbs.; his capacity was 464 cubic inches. The minimum was 46 cubic inches, and occurred in a dwarf measuring 29 inches in height, and weighing only 40 lbs. Modern *dress* impedes respiration, for a man who could only expire 130 cubic inches when his clothes were on, accomplished 190 cubic inches when unclothed. The *posture* of the body modifies the vital capacity; for if, in the attitude of standing, it be 260 cubic inches, in the sitting posture it is 235, in the recumbent position 230, and in lying on the face 220. The degree of distension of the stomach, likewise influences the vital capacity of the chest. *Corpulency*, in persons weighing more than 160 lbs., diminishes the vital capacity at the rate of 1 cubic inch for every additional pound up to 196 lbs., or 14 stone weight. *Practice* with the spirometer increases the power of forcing up the inner cylinder, whilst nervousness and awkwardness operate the other way. Hence, in the use of this apparatus, allowance must be made for all the above-mentioned disturbing influences; and, it is certain, that the so-called vital capacity is not strictly related to the muscular power of the individual. Nevertheless, it is a valuable addition to our means of diagnosis, as to the condition of the lungs; the obstructed state of those organs in the earlier stages of phthisis, and the deficient respiratory movement dependent upon this condition, cause a serious diminution in the vital capacity, as compared with the normal standard in persons of the same sex, age, and stature. A diminution of 16 per cent. in the normal capacity, is said to indicate a diseased condition (Hutchinson); but care must be taken to allow for the effects of congestion, and of abdominal disease.

If in a person 5 feet 6½ inches in height, the breathing air averages, during the twenty-four hours of work, rest, and sleep, 20 cubic inches at each inspiration, and the number of respirations per minute for the day and night be taken at 18, the quantity of air inspired and expired by an adult man of mean stature, in one minute, would be 360 cubic inches. This would give 518,400 cubic inches or 300 cubic feet, for the twenty-four hours. This amount is less than the total daily quantity as estimated by Valentin, which is 688,348 cubic inches; less also than the quantity, viz., 686,000 cubic inches, found by Edward Smith to be the average in four adults, of a mean height of 5 feet 10½ inches, during a state of rest. During ordinary exercise, the estimates of the last-named observer, give 804,780 cubic inches; in the case of the actively employed laborer, 1,568,390; and during a day's work, including twelve hours of Alpine exercise, 1,764,000 cubic inches. Vierordt's estimate for the twenty-four hours, is 732,000 cubic inches; but that author assumes the quantity of air inspired per minute to be 450 cubic inches. Edward Smith found it to average 500 cubic inches in the day, and 400 during the night, in four persons of the mean stature of 5 feet 10½ inches.

It has been estimated that, with a vital capacity of 200 cubic inches, the force employed in making the necessary full inspiration is equal to the raising of 300 lbs. weight upon the surface of the chest; but in forcible expiration, the power exerted is much greater. In ordinary breathing, supposing the quantity of air inspired to be 20 cubic inches, the resistance overcome by the inspiratory muscles is equal to a weight of 200 lbs.

Changes in the Air from Respiration.

The air expired from the chest differs in three respects from that which is inspired. It is increased in *temperature*, except of course when the inspired air is already hotter than the body itself. It contains, as a rule, more *moisture*, unless when it is previously, and exceptionally, saturated with watery vapor. Lastly, it undergoes important changes of *composition*, the chief of which consist in a loss of oxygen and an addition of carbonic acid.

The *increase of temperature* in the expired air is regulated by the temperature of the air taken into the lungs. When the surrounding air is cold, the increase is not quite so great as when its temperature is nearer that of the body; but the difference is less than might be supposed. With the thermometer at from 50° to 68°, the expired air has a temperature of 95° to 100°; whilst if the external temperature be 32° or freezing-point, then the expired air is not more than 86°. According to Valentin, however, in ordinary breathing the temperature of the expired air in the winter is only 1° less than that of the air expired in summer. In tranquil respiration, the expired air becomes comparatively warmer than in rapid breathing, as if, in the latter case, sufficient time was not allowed for the air to gain warmth. The increased warmth of the expired air, necessarily causes an increase of volume, but this is partly neutralized by a small loss of air in respiration, owing, as we shall see, to the absorption of more atmospheric oxygen by the lungs, than is equal to the carbonic acid exhaled. The actual volumes of the inspired and the expired air, are as 97.2 to 99.5; but, after the equalization of their temperature, the volume of the expired air is so reduced that it becomes less, by the amount of oxygen absorbed in excess of that of the carbonic acid given out.

The *surplus of watery vapor* in the expired air, as compared with that in the inspired air, depending on the hygrometric condition of the air before it is breathed, it becomes difficult to estimate the daily quantity of water actually exhaled from the lungs. This has, however, been variously calculated at from 11 to 16 oz., or, as an approximate average, at 15 oz., per diem; but the quantity, according to modifying circumstances, ranges from 6 to 27 oz. The source of this vapor is the water of the blood, and thus, like the aqueous basis of the secretions and excretions, it must assist in regulating the degree of fluidity of the blood. Some of the vapor of the breath, comes from the fauces, mouth, and nose, but the greater part, from the air-cells and air-tubes. It would seem that a small quantity of hydrogen is converted into water in the respiratory process, and may also come to be thus expelled. After taking food, or alcohol, the pulmonary exhalation is said to be increased, but it is lessened during fasting. As a rule, the expired air is almost completely saturated with vapor, holding as much as it can dissolve, according to its temperature; but this is true only of calm respiration; for in hurried breathing, neither can the air be elevated to its highest temperature, nor can it be completely saturated with moisture. The more calmly air is breathed, the greater the loss of water by the lungs. Lastly, the *drier* the inspired air, the greater must be the amount of pulmonary exhalation; for, in breathing air already perfectly saturated, only such further quantity of water can be added to it, as its increase of temperature in the lungs will enable it to dissolve. The inhalation of actual vapor stops the pulmonary exhalation, So, too, when the temperature of the surrounding air is 100° or 102°, and it is already saturated, the temperature of the blood itself being about the same, no further exhalation of water from the lungs is possible; nor can the skin then give off more watery vapor. Under such circumstances, the kidneys, and perhaps also, though to a slight extent, the mucous membrane of the intestines, excrete more actively. The pulmonary exhalation contains, besides water, traces of carbonic acid, ammonia, chlorides, urates, and even some albuminoid substance, and it readily undergoes decomposition.

The changes in the *composition* of the expired air are regulated by that of the inspired air. The composition of the atmosphere in free space is singularly uniform in different localities, and at different altitudes. By weight, supposing it to be dry, it contains nearly 77 parts of nitrogen, and 23 of oxygen. Besides these, its essential constituents, it contains a small percentage of carbonic acid, disengaged into it by terrestrial agencies, partly physical, such as volcanoes and springs, partly chemical, as the decomposition of carbonaceous matter, but chiefly organic, as from the respiration of plants; the atmosphere also presents minute traces of nitric acid, ammonia, and carburetted hydrogen, from the decomposition of animal and vegetable substances. In towns it often contains sulphuretted hydrogen and sulphurous acid, from the combustion of coal; in the neighborhood of chemical works it may also be charged with chlorine, mineral acids, and metallic substances. Under certain circumstances, a very pure air contains the important substance known as *ozone*, which is now usually regarded as a modification of oxygen. It is most abundant in sea air, in early morning, and, in England, with southwest or west winds; it is almost absent with east winds, and is quite so in the centre of large towns, and in the atmosphere of dwellings.

By volume, dry air consists, in round numbers, of 80 volumes of nitrogen, and 20 of oxygen, or of 4 volumes of the former to 1 of the latter. A closer analysis gives 79 volumes of nitrogen to 21 of oxygen. The quantity of carbonic acid gas averages .04 volumes per cent., or, as it is commonly expressed, 4 parts in 10,000.

The effect of a *single respiration* on the composition of the air breathed, is first, to remove from 100 volumes of air about 5 volumes of oxygen, *i. e.*, about $\frac{1}{4}$th its normal quantity of that gas; and, secondly, to add to it about 4 volumes per cent. of carbonic acid gas. Besides this, however, the quantity of nitrogen is slightly increased; and ammonia, carburetted hydrogen, certain salts, organic matter, and various undetermined volatile substances, are added to the air in the respiratory process.

The annexed Table from Vierordt shows the percentage composition in volumes of air before, and after, it has been *once* breathed; the air being, in both cases, supposed to be perfectly dry. The minute trace of carbonic acid gas in unbreathed air, only .04 per cent., is here neglected.

	Atmospheric Air.	Air once breathed.
Nitrogen,	79.2	79.3
Oxygen,	20.8	15.4
Carbonic Acid,	—	4.3
Loss,	—	1
	100	100

During a single respiration, therefore, 5.4 parts of oxygen disappear, being absorbed by the lungs; whilst only 4.3 parts of carbonic acid are exhaled from those organs. Moreover, a minute quantity of nitrogen appears to be given off into the expired air. Lastly, owing to the excess of oxygen absorbed over the carbonic acid exhaled, there is a loss of 1 per cent. of the air inspired. These results are founded on nearly 600 observations; but, as we shall hereafter see, individual experiments exhibit remarkable deviations, according to numerous circumstances.

Absorption of Oxygen.—The quantity of oxygen absorbed in respiration is determined by careful examination of the quantity left in the expired air. This is done by using pyrogallic acid, which greedily attracts it, to take it up, or by combining it with hydrogen by means of the electric spark. There is no doubt that the greater portion of the oxygen absorbed, which in a single respiration is about $\frac{1}{4}$th the total quantity in the air, combines somewhere, and in some way, with carbon, to form the carbonic acid which is exhaled. But as the carbonic acid produced exactly equals in volume the oxygen concerned in its production, the surplus of oxygen absorbed over the carbonic acid exhaled must remain in the system, and is probably therein combined with hydrogen, or with the sulphur and phosphorus of the albuminoid constituents of the body. In Man, from $\frac{1}{5}$th to $\frac{1}{7}$th of the total amount of oxygen absorbed does not reappear in the carbonic acid, but remains to be combined with other oxidizable substances. In dogs fed upon carbhydrates, such as starch or sugar, or even upon milk, $\frac{9}{10}$ths of the oxygen absorbed are returned as carbonic acid, only $\frac{1}{10}$th remaining in the system; if large quantities of flesh are eaten, more of the oxygen, *i. e.*, $\frac{1}{5}$th, is retained; lastly, when fat alone is consumed, $\frac{3}{10}$ths are retained, as if a pure fat diet stimulated the oxidation of the nitrogenous tissues. (Regnault and Reiset.) Again, in Herbivorous animals which consume many carbhydrates in their food, the proportion of oxygen retained in the system is exceedingly small; whereas, in Carnivorous animals, the food of which is chiefly nitrogenous, but also fatty, a very large proportion is retained. (Dulong and Despretz.) In starving animals also, which practically live carnivorously, *i. e.*, on their own tissues, a large proportion of the oxygen is retained, amounting even to $\frac{2}{5}$ths of the total quantity absorbed.

Elimination of Carbonic Acid.—The fact of the elimination of this gas from the lungs, may be shown by blowing slowly through a tube into lime-water, which soon becomes turbid from the formation of carbonate of lime, more especially as the last quantities of air are being expelled from the chest. The determination of the quantity of carbonic acid gas given off in respiration, is extremely difficult, notwithstanding the ingenuity of the methods employed for this purpose.

The simplest method, used by Prout, Dumas, Vierordt, and others, consists in causing a person to inspire air through the nose, and expire it through a tube, held in the mouth, into a closed bag or receiver; and then in analyzing the expired air, by agitation with lime-water or with a solution of caustic potash, either of these substances absorbing the carbonic acid, which can thus be measured. The oxygen has, at the same time, been estimated, by means of pyrogallic acid, or by deflagration with hydrogen, by means of the electric spark. (Vierordt.) Such a method, excellent for individual trials, is not adapted for general or comparative experiments; because the same person does not, under such conditions, breathe equally, at all times, even after considerable practice; nor can different persons breathe equally, in regard to each other, differences in the depth and duration of the respirations rendering a comparison of the results fallacious.

For these reasons, observations have been made on men and animals, placed in suitable hermetically closed chambers, and able to breathe with less, or even no restraint. The *breathing-chamber* communicates with the air by means of a small supply tube on one side, and on the other is connected by a tube with an *aspirator*, *i. e.*, a second closed chamber filled with water; according as this water is permitted to flow from the aspirator, air is withdrawn from the breathing-chamber, whilst fresh air enters by the supply tube. To insure the absence of carbonic acid from the air employed, the supply tube has a bend in it, containing a solution of caustic potash. The tube connecting the breathing-chamber with the aspirator, has also a bend containing asbestos, moistened with concentrated sulphuric acid, for the absorption of the exhaled water; besides this, it is fitted with a Liebig's potash-tube, for fixing and weighing the carbonic acid formed in respiration, and also with another bent tube, for again desiccating the remaining air. By such an apparatus, the quantity of air passing through the air-chamber, and the quantity of carbonic acid produced in any given time, can be determined. (Dulong and Despretz's experiments on Animals.) In observations on men, the body has been inclosed in a second smaller box, so that the head alone projected into the air-chamber; the products of cutaneous respiration and exhalation are thus separated from the pulmonary respiration and exhalation, the gases and vapor given off by the skin being retained in the smaller box, and those given off by the lungs being discharged into the breathing-chamber. (Scharling's and Hannover's experiments on Man.) By others, the face alone has been covered with a tight-fitting mask, through which a stream of air enters by two valved openings, and from which it is drawn off through a tube into a receiver, by means of an air-pump. (Andral and Gavarret.) Instead of supplying the breathing-chamber, in which animals have been placed, with pure atmospheric air, known quantities of oxygen, proportioned to the quantity of carbonic acid formed, have been introduced. The arrangements necessary for the gradual absorption of the carbonic acid and the introduction of fresh oxygen, render this apparatns somewhat complex, but interesting results have been obtained by it. (Regnault and Reiset.) In long-continued experiments, however, the quantity of nitrogen in the chamber gradually increases by exhalation from the animal's lungs; hence the atmosphere breathed by it is no longer normal, and the respiration is modified accordingly.

The experiments of Pettenkofer and Voit, undertaken with the pecuniary assistance of the late King of Bavaria, are still more elaborate, costly, and complete. A large closed breathing-chamber is provided, in which the person experimented upon can live and breathe for many hours, as easily as in an ordinary apartment; and through it, copious streams of air, as much as 75 cubic metres per hour, are drawn, by means of a double pump worked by a small steam-engine, the total quantity passed through being accurately registered, after desiccation, by a gas-meter interposed between the chamber and the pump. Atmospheric air is admitted to the chamber by proper apertures, and the amount of carbonic acid gas and water already contained in it, is accurately determined. The contaminated air leaves the chamber by two tubes, one passing from near the ceiling, and the other from near the floor, which then join a common tube; this tube leads into a desiccating box, from which the dried air passes through the gas-meter to the cylinders of the double air-pump. To absorb and measure the whole of the carbonic acid gas contained in this large stream of air, the total product of the respiration of the person living in the chamber, would be an inconvenient process; accordingly, a small portion of the contaminated air is diverted for that purpose, through an analyzing apparatus, into which this portion of the air is drawn by a peculiar suction- and pressure-pump, moved by the steam-engine which works the larger pump. This portion of air passes in succession through an apparatus which absorbs and measures, first the water, and then the carbonic acid contained in it, and afterwards through a desiccating box and small gas-meter, by which it is ultimately measured. Its quantity, compared with the larger quantity drawn through the main tube, furnishes the means of calculating the total quantity of carbonic acid eliminated by the person confined in the breathing-chamber, in a given time. The quantities of carbonic acid gas and water, formed by the combustion of a stearin candle in the chamber, may be determined by this apparatus as correctly as by the ordinary process of organic analysis.

Dr. E. Smith has employed a small mask, which fits tightly over the mouth and nostrils, and is provided with a valved inlet and outlet. The air is inspired through, and measured by, a *spirometer*, consisting of a delicate gas-meter. The expired air passes through a desiccator, containing sulphuric acid to absorb watery vapor; then through a gutta-percha box, divided into many chambers and cells, containing caustic potash, and offering a surface of 700 square inches, so as to abstract the carbonic acid; and, lastly, through a second desiccator to retain any moisture carried off and lost, from the potash box. The increase in weight of the mask, with the connecting-tube and first desiccator, shows the amount of vapor exhaled from the lungs; whilst the addition to the joint weight of the potash box and the second desiccator, gives the weight of the carbonic acid expired.

Regnault and Reiset, Pettenkofer and Voit, and Dr. Edward Smith, have endeavored to determine not merely the amount of carbonic acid eliminated in ordinary breathing, but also the influence of those conditions which modify that amount, and likewise have attempted to obtain data for comparing the quantity of carbonic acid formed and of oxygen taken in, with the animal heat evolved.

Some only of the results obtained by various observers, can here be quoted. Dumas, calculating that by an adult male, of average size, 320 cubic inches of air are respired in one minute, and that this contains, on expiration, 4 per cent. of carbonic acid, concluded that about

13 cubic inches of carbonic acid are exhaled per minute, which would be equal to a total of $5\frac{1}{2}$ oz. av. of carbon thrown off by the lungs in twenty-four hours. The calculations of Valentin and Brunner, Davy, Allen, Pepys, and Lavoisier, agree closely, yielding, as a general result, 8 oz. of carbon excreted by the lungs in twenty-four hours. Andral and Gavarett estimated the daily quantity at 9 oz.; Vierordt says that it varies from 5 to 8 oz. Dr. E. Smith found, as an average of eight experiments, the daily quantity, in a state of rest, in four men, whose mean height was 5 feet $9\frac{3}{4}$ inches, to be 7.144 oz.; the extremes were 5.6 oz. and 7.85 oz. With an ordinary amount of exercise, he estimates the quantity at about $8\frac{1}{2}$ oz., and in a working man fully engaged in labor, at rather more than $11\frac{1}{2}$ oz.

Adopting as a basis of calculation, the estimate already given at p. 821, viz., of 300 cubic feet, or 518,400 cubic inches, as the total quantity of air respired in twenty-four hours, by an average-sized adult male, 5 feet $6\frac{1}{2}$ inches in height, allowing for the effects of work in the day and the influence of repose at night, and, moreover, calculating that the average quantity of carbonic acid in the air when expired is 4 per cent., then 20,736 cubic inches of carbonic acid would be given off in the twenty-four hours. As 100 cubic inches of carbonic acid gas weigh 47.26 grains, this quantity would weigh about 9800 grains, which would contain 2672 grains, or rather more than 6 oz. av. of carbon. This is perhaps a fair calculation for a man of medium size, not engaged in any special exercise or labor.

Elimination of Nitrogen.—The nitrogen of the atmosphere, which serves to dilute the oxygen, is, to a slight extent, absorbed by the blood, for that fluid always contains nitrogen in a state of solution. Nitrogen, however, is also given off from the blood through the breath; and the balance appears to be rather in favor of the process of elimination. The quantity thus thrown off by warm-blooded animals, is so minute as never to exceed $\frac{1}{50}$th part of the oxygen consumed (Vierordt); sometimes it is less than $\frac{1}{100}$th part. (Regnault and Reiset.) The source of this small excess in the nitrogen exhaled, was at one time supposed to be the nitrogenous aliments, the quantity of nitrogen excreted by the kidneys, skin, and intestines, being supposed to be less than that taken in the food. The quantity of nitrogen not accounted for in the renal, cutaneous, and intestinal excretions, has been said to be equal to $\frac{1}{75}$th of the oxygen consumed in an adult, which nearly agrees with the estimate of Regnault and Reiset above mentioned. But, according to Voit and others, however, all the nitrogen of the food which is actually subjected to metamorphosis in the blood, is accounted for in the nitrogenous constituents of the urine. The minute and unimportant excess in the expired air may, therefore, be derived from the atmospheric air, which is swallowed with the saliva, food, and drink, and is taken up by venous absorption; its oxygen being utilized in the blood, the nitrogen escapes through the walls of the pulmonary capillaries and the air-cells, into the breath. In favor of this view, it may be added, that the decomposition of nitrogenous substances in the system, so as to yield free nitrogen, is unknown; that in starving animals, which probably swallow less air, nitrogen is not given off in excess, but some of it seems rather to be absorbed; and lastly, that whilst the quantities of oxygen and carbonic acid in arterial and venous blood differ in a constant manner, the quantity of nitrogen follows no such rule, and even varies in both kinds of blood.

Other Substances Eliminated in the Breath.—Chloride of sodium, hydrochlorate of ammonia, uric acid, and urates of soda and ammonia, have been found in expired air. The carbonate of ammonia, frequently present, is sometimes partly derived from decaying animal matter between, or belonging to, the teeth; but some of it is believed, by certain physiologists, to come from the blood. The carburetted hydrogen occasionally found in the breath, proceeds from the blood, into which it enters by absorption from the alimentary canal. The presence of organic matter in the breath is detected by passing the expired air through strong sulphuric acid, which, in a prolonged experiment, becomes brown. According to recent inquiries, this organic substance is albuminoid, and when collected and allowed to putrefy, becomes extremely offensive; when accumulated in small and over-crowded rooms, it has a fetid, repugnant odor. It may possibly be the medium, or vehicle, of certain contagions thrown off by the breath; it is not to be confounded with the bad smell from carious teeth, or from ulcers in the mouth, pharynx, or air-passages. Many odorous substances may exist in the breath, derived from food, drink, or medicines, such as cheese, alcohol, or perhaps aldehyde, given off after the use of alcoholic beverages, the volatile principles of garlic, onions, and spices, ethers, chloroform, camphor, musk, and many other medicinal substances. Phosphorus dissolved in oil, and injected into the veins of an animal, is given off by the lungs in some imperfectly oxidized state, so that the breath is luminous as it passes from the nostrils.

Effects of Respiration on the Blood and Tissues.

Changes in the Color of the Blood.—The most obvious change effected in the blood, as it passes through the lungs, is that from the dark purple venous, to the bright scarlet arterial, tint. A similar change of color takes place on agitating dark venous blood with air, and, still more quickly, with oxygen; it also occurs when venous blood is introduced into a moistened bladder, and suspended in air or in oxygen gas. The causes of this change of color have been the subject of much inquiry.

It is found that on adding water to bright arterial blood, it becomes of a dark hue; whilst strong solutions of common salt, saltpetre, or bicarbonate of potash, when added to venous blood, immediately brighten its color; this effect has been attributed, either to the direct action of the saline substances, or else to the change which they produce in the specific gravity of the blood. It has been supposed that the red corpuscles, by exosmosis of fluid into the denser solution of the saline substance, shrink, and thus, from being slightly biconcave, become deeply so. On the other hand, the addition of water has the effect of producing an endosmosis of fluid into the corpuscles, and so causes them to swell, and assume a flat or even biconvex form.

These opposite changes of shape have been supposed to modify the power of the corpuscles to absorb colored light, more being absorbed when they are swollen, and less when they are shrunk. But, according to Professor Stokes, this explanation is inconsistent with optical principles, and the change of color is due to a modification in the *refractive* power of the corpuscles; in the shrunken state, their refractive power is increased, and, accordingly, a larger amount of reflection takes place from the surfaces of contact of the corpuscles with the surrounding fluid; whilst in the distended state, their refractive power is diminished, and less reflection takes place from their surfaces. But, although the brilliant color, produced by the addition of strong saline solutions to the blood, and the dark hue occasioned by diluting it with water, may be thus satisfactorily explained, the natural alterations of color produced in the blood by the respiratory changes cannot be so accounted for; though venous blood is of somewhat less specific gravity than arterial, yet there is no evidence of its containing fewer salts; moreover, direct observation has failed to detect any difference in form between the corpuscles of the two kinds of blood; and lastly, the inadequacy of such a purely physical explanation is proved by the fact that, even when the red corpuscles are entirely dissolved, or when pure solutions of cruorin or the coloring substance of the blood, are employed, precisely similar changes in color ensue, from alternately agitating them with oxygen, and carbonic acid, in the former case the color being brightened, and in the latter rendered dark. The nature of the changes thus induced in the cruorin of the blood, has been revealed by the photo-chemical discoveries of Hoppe and Stokes, in which the so-called *spectrum analysis* is employed, to detect most recondite changes in the cruorin.

The formation of the prismatic *solar spectrum*, by passing a beam of sunlight through a prism, has already been explained (p. 431). In this spectrum, when sufficiently magnified, it has long been observed, that numerous, fine, dark lines exist, the lines of Frauenhofer; these are owing partly to the presence of vapor in the air, which refracts some of the light, but chiefly to the absence, in the light examined, of luminous rays of certain degrees of refrangibility; the consequence of which is, that some parts of the spectrum are left unoccupied by any light whatever. In the solar spectrum, Frauenhofer described 80 *dark bands* or *lines;* but 2000 are now recognized. Light obtained from different sources, as by the combustion of different substances, or ordinary light first passed through transparent bodies, solutions, or even through the vapors of volatile substances, or proper gases, either *colorless* or *colored*, and afterwards transmitted through a prism, also forms a spectrum; but on comparing the magnified spectra of different substances, it is found, in many of them, that the dark bands differ in number, position, width, and intensity; and, moreover, that in the case of certain lights, which are colored, *color bands* of different position, number, width, and intensity, make their appearance. The yellow color band of sodium is a remarkable example of this.

The *dark bands*, sometimes called *absorption bands*, and the *color bands*, being characteristic and constant, for certain substances, they constitute most delicate means of detecting, and discriminating between, such substances. This is done by the *spectroscope*, an instrument consisting essentially of a tube with a slit at one end, a prism at the other, and a small magnifying glass with which to magnify the spectrum. This method is the so-called *spectrum analysis*, by which, not only have new substances been detected in chemical processes upon the earth, but some at least of the constituents of the luminous atmospheres of distant stars have been determined. It has also been employed to follow the entrance of peculiar substances, such as lithium and cæsium, into the blood and tissues of living animals, to measure their rate of absorption, their preference for particular tissues, and their periods of excretion from the body. (Bence Jones.) To the same observer we owe very interesting researches, in which the *fluorescent* property of quinine (p. 431) is made use of, to follow that substance into, and out of, the living economy, by its presence or absence in the crystalline lens of the eye. It, moreover, appears that a peculiar animal substance, also fluorescent, and therefore named by Dr. Jones, *quinoidin*, is constantly present in the animal body.

Amongst other results of the spectrum analysis of colored solutions, it was discovered by Hoppe, that dilute solutions of blood produce *two* peculiar *dark* absorption bands of great beauty and distinctness, situated in the spectrum, between the D and E lines of Frauenhofer, and having a remarkably bright *intermediate color* band. He showed that this spectrum was formed by the colored blood of animals generally; that the red coloring substance seemed to remain unchanged by the action of alkaline carbonates and caustic ammonia, for its spectrum remained unaltered; but that it was instantly decomposed by acids, and more slowly by caustic alkalies, a substance being then produced, which causes different absorption bands, and corresponds with the hæmatin of Lecanu.

This subject has since been further investigated by Professor Stokes. To examine the natural blood spectrum, he placed a small portion of blood well diluted with water, or a watery extract of the clot, in a test-tube; this being held up to the light, behind a fine slit in a piece of black card or a metal plate, and looked at through a prism, the two characteristic, sharply-defined, dark absorption bands, with the intermediate bright streak, were readily seen. On adding to the colored solution a reagent capable of *abstracting oxygen* from it, a remarkable change occurred in the spectrum. First, it became a little darker; but, besides this, instead of the *two* dark bands with their intermediate bright streak, a *single*, broader, and less defined band was now seen, situated nearly opposite the place of the bright band in the spectrum of the simple solution. Since the solution of blood is alkaline, and since acids, as just mentioned, decompose its coloring substance, it was necessary to employ a peculiar deoxygenating agent; the one selected was a solution of protosulphate of iron, containing a small quantity of tartaric acid, which prevents the precipitation of the iron by alkalies; this was rendered slightly alkaline by a little soda. On next exposing the deoxygenated and altered colored solution to the air in a shallow vessel, or on agitating it with air, by shaking it in a long tube, it was found that the color again became brighter, and that, on examination with the prism, the characteristic dark bands, with the intermediate bright one, again appeared. These changes were evidently attributable to the reoxygenation of the coloring substance by the oxygen of the air. This beautiful experiment realized the supposition previously entertained by Stokes, that he might imitate, and possibly explain, the change of color of arterial into venous, and of venous into arterial blood. That the single band of the altered solution does not belong to the reagent, is shown by examining that separately; and that it is not produced by a compound of the reagent with the coloring substance, but simply by deoxygenation of the latter, is proved by the same effects being produced by other deoxidizing agents, such as protochloride of tin, and hydrosulphuret of ammonia, and also by the ordinary and well-known displacement of oxygen, by means of carbonic acid. Moreover, these reagents have themselves no power to produce the newly-observed color band.

From these experiments, it is concluded by Stokes, that there exists in the blood a *natural coloring matter*, which might be named *cruorin*, capable, like the coloring matter of indigo, of assuming, by alternate abstraction and reintroduction of oxygen, two states of oxidation, in which it differs in color and in its action on the spectrum. The hæmatin of Lecanu is an artificial compound, produced by the decomposition of this cruorin by powerful acids, and is named by Stokes *brown hæmatin*, to distinguish it from *red hæmatin*, formed by the oxidation of the brown variety, both of which show different absorption bands to those of cruorin.

The cruorin in its bright condition, is named *scarlet* cruorin, and in its dark condition, *purple cruorin;* the former gives the spectrum with two dark bands and an intermediate light one, and the latter, that with a single dark band. The purple cruorin, or deoxygenated kind, is supposed to exist in venous blood, and the scarlet, or oxygenated kind, in arterial blood. The evident attraction of cruorin for oxygen, is supposed to account for the absorption and combination of that gas with the blood; and thus, also, for the special attraction or affinity of the red corpuscles for oxygen, of which, indeed, they have been often named the *carriers.*

As apparently opposed to these conclusions, it is found that ordinary venous blood exhibits the spectrum of the scarlet cruorin, and not that of the purple cruorin; but this, as observed by Stokes, may merely show that most of the cruorin in venous blood is still scarlet cruorin, the coloring substance being only partially converted into the purple condition. Venous blood, indeed, like arterial blood, still contains oxygen, as well as carbonic acid, though in different proportions; and, although it is unequal to the perfect maintenance of the functions of the muscular and nervous substance, it is still better than no blood at all. (Brown-Séquard.) Moreover, extensive hemorrhage is not necessarily fatal; and persons affected with chlorosis exhale carbonic acid as freely as those in health. It is possible, also, that carbonic acid may act less powerfully when the blood is undiluted, than when, as in experiments, it is mixed with water.

The cruorin of the blood being supposed, in the act of respiration, to undergo oxygenation as it assumes its scarlet color, its deoxygenation or reduction may be effected by substances contained in the blood, which themselves undergo oxidation at its expense. Such a change certainly takes place in blood diluted and put aside before putrefaction takes place, the spectrum being distinctly altered to that of purple cruorin, and being changed back again to that of scarlet cruorin, by agitation with air. A temperature as high as that of the blood in the body facilitates these changes.

The possible mode of occurrence of such alternate changes in the blood in the systemic and the pulmonary capillaries, is illustrated by Stokes, by first reducing or deoxygenating, a solution of scarlet cruorin, by means of a slightly alkaline solution of the protoxide of tin in tartaric acid, and then reoxygenating it, by agitation of the altered colored solution with air. If the mixture be now allowed to stand for two or three minutes, the coloring matter is again slowly deoxidized; by agitation it is once more oxidized; and so on for a number of times. In this experiment, the purple cruorin absorbs oxygen more readily than the salt of tin does; but afterwards, it slowly parts with oxygen to that salt.

In the same way, the purple cruorin, as it passes through the lungs, absorbs oxygen by a special affinity, and then in circulating through the systemic capillaries, it is partially deoxygenated, to supply the wants of the disintegrating tissues, by a so-called *parenchymatous respiration;* on returning to the lungs, it is once more reoxygenated.

The various alterations in the color of the blood, noticed in different conditions, accord with this conclusion. Thus the blood is unusually dark as it returns from the muscles, and the depth of its color is in exact proportion to the activity of those muscles, when, as we shall see, it also contains the most carbonic acid. On the other hand, the venous blood returning from glands in a state of active secretion, is of a bright scarlet hue; whereas, when the glands are inactive, it is dark (pp. 264, 522, 756.) In the latter case, the quantity of blood passing through the gland is small; nutrition proper is going on, and a proportional quantity of carbonic acid is formed and taken up; whereas for active secretion, the conditions existing are, a large supply of blood, with a proportionally less amount of deoxygenation. Again, it has been noticed that, at high temperatures, there is much less difference in the color of the arterial and venous blood-current, and also a less amount of respiratory interchange; whereas, at low temperatures, the difference of color is greater, and so likewise is the activity of the respiratory process. In anæmia, in the state of hibernation, and also in sleep, the venous blood has the same color as the arterial; and both the pulmonary and the parenchymatous respiration are imperfectly performed. Lastly, in asphyxia and in cholera the blood is exceedingly dark, and, in both diseases, contains unusually large quantities of carbonic acid.

A further result of these researches, is to show that the oxygen carried through the body by the blood is, to a large extent, actually chemically combined with it, *i. e.*, with the cruorin of the red corpuscles, though some must be merely dissolved in the liquor sanguinis, and all must pass through that fluid, to enter and escape from the corpuscles. But that a certain portion of the oxygen is retained in the liquor sanguinis, is shown by the fact, that the clot of dark venous blood assumes a bright hue when placed in the serum of arterial blood, or even of the scarlet venous blood returning from an actively secreting gland. It is uncertain whether any of the carbonic acid is specially attached to the red corpuscles; it would rather seem not. The coagulum of the scarlet venous blood from a gland, as well as that of arterial blood, becomes darkened, when placed in the serum of dark venous blood; so that carbonic acid certainly exists in the liquor sanguinis of venous blood. It appears to be partly dissolved in the serum, and is partly, perhaps, in a state of loose chemical combination.

Changes in the Fibrin of the Blood.

During the aeration of the blood in the lungs, and perhaps as a special result of the action of oxygen absorbed from the air, the amount of fibrin is increased in arterial, as compared with that in venous blood; a difference also exists in the coagulating power of the arterial fibrin, which forms a firmer clot than that of venous blood.

The influence of oxygen, in increasing the amount of fibrin, has been shown, by causing rabbits to breathe pure oxygen for a short time, and also by inducing an unusual activity of the respiratory movements by means of electricity applied to the spine and chest. In these experiments, the quantity of fibrin in the arterial blood was increased respectively to 2.4 and 2.9 parts in 1000 of blood; whereas in the ordinary arterial blood, the proportion found was only 1.65. (Gardner.) The fibrin is, of course, produced at the expense of some other albuminoid body, either globulin or albumen. Even out of the body, a substance somewhat like fibrin, though not positively determined to be fibrin, has been produced by transmitting oxygen gas (A. H. Smee), or ozone (Gorup-Besanez), through a solution of albumen.

Change in the Temperature of the Blood.

Numerous attempts have been made, to determine whether there be any difference, and if so, what difference, between the temperature of the blood, before and after it has passed through the lungs. The older physiologists, and also some recent observers (Harley and Savory), have maintained that the blood in the left ventricle is warmer, by from 1° to 2°, than that in the right ventricle; and, in accordance with this, it has often been supposed that the oxygen combined directly with certain constituents of the blood in the lungs, to produce the whole of the carbonic acid given off in respiration. But it is now known that this latter supposition is incorrect. Many observers, moreover, have found that the blood in the left side of the heart, is not so warm as that in the right cavities, owing, as they maintain, to a cooling process, caused by the entrance into the lungs of air of a lower temperature than the blood, and by the evaporation of moisture from the internal pulmonary surfaces. This does not affect the general conclusion, that the venous blood returning from the limbs, is cooler than the arterial blood of the same parts. We shall revert to this subject in the Section on Animal Heat.

Changes in the Gases of the Blood.

It has been elsewhere noticed (pp. 614, 616) that the vapor of water and also many volatile substances and gases are readily *absorbed* into the blood by the lungs; and, indeed, one of the two chief phenomena of respiration, viz., the entrance of oxygen into the blood, illustrates the absorptive power of the pulmonary mucous membrane.

This absorption of oxygen from the inspired air by the venous blood brought to the pulmonary capillaries, is associated with the evolution of carbonic acid which escapes from that venous blood, and is added to the air about to be expired. These two joint interchanges of the gaseous elements of the air and of the blood are essential steps in the conversion of venous into arterial blood. That the blood participates in these changes is shown by the fact that venous blood contains less oxygen and more carbonic acid than arterial blood, which, on the other hand, contains more oxygen and less carbonic acid, as shown by the following table. (Magnus.)

	Oxygen.	Carbonic Acid.
100 vols. of Venous blood, . .	5 vols. . .	25 vols.
100 vols. of Arterial blood, . .	10 vols. . .	20 vols.

It has also been found that the proportions of oxygen and carbonic acid in venous blood returning from muscles at rest, are 7.5 and 31, and from muscles *in action*, 1.265 and 34.4; whilst in arterial blood the proportions are 17.3 of oxygen and 24.2 of carbonic acid. (Sczelkow.) According to Magnus, arterial blood contains twice as much oxygen as venous blood generally, whilst, in the special case of the blood from muscles, the proportion is at least 2.3 to 1. Again, ordinary venous blood contains $\frac{1}{5}$th more carbonic acid than arterial, and that from muscles at rest, about $\frac{1}{4}$th more.

The interchanges of oxygen and carbonic acid between the air and the blood, which characterize respiration, have, through the researches of Dalton, Draper, and Graham, received a partly physical and a partly chemical explanation. The elimination of urea and uric acid by the kidneys, and of certain excretory ingredients of the bile, is accomplished by organic vito-chemical processes performed by certain special epithelial cells; but the absorption of oxygen by, and the elimination of carbonic acid from the lungs, or other respiratory organ, are purely physical and chemical processes. These may, indeed, be imitated artificially out of the body; for, as already mentioned, if a moist bladder be filled with venous blood and be suspended in atmospheric air or oxygen, the surface of the blood in contact with the bladder soon becomes scarlet, and, during that change, oxygen is absorbed, and carbonic acid is given out from it through the moistened bladder. It is remarkable that a function of the animal economy, so immediately and constantly necessary to life, is removed from the contingencies surrounding a purely organic process, and is brought into the sphere of physical and chemical actions. It is also worthy of remark, that the physical processes which accomplish the escape of the deleterious carbonic acid gas from the blood, and mix it with the air, also aid in the entrance of the essential purifying and stimulating oxygen from the air into that fluid. The processes in question are the *diffusion of gases*, or the tendency of dry gases to diffuse into each other, and their mutual diffusion when in a dissolved condition.

It was shown by Dalton, that, even when a light gas, such as hydrogen, is poured into a glass jar on to the surface of a heavy one, such as carbonic acid, or when a bottle full of the light gas is inverted over another bottle containing a heavy gas, with their mouths applied to each other, the gases do not remain stationary, but are mutually transported into each other against gravity until they have intermixed in certain definite proportions. The facility with which they intermix is such, as to have been expressed by the phrase that each gas offers no more resistance to the other than would an actual vacuum. This simple intermixture is called the *diffusion of gases;* it takes place with a definite energy, irresistible and invariable, when the conditions exist for its exercise. The force with which it takes place, and its extent in any particular instance, are said by Dalton to be generally inversely as the densities or weights of the two gases respectively. Subsequent experiments on a most extended scale enabled Graham to determine the true numerical expression or law of this diffusive power or energy of gases, viz., that the rate of diffusion of any gas, if dry and pure, is inversely as the *square root* of its *density* or specific gravity. Graham showed, moreover, that this diffusion takes place through narrow tubes and through porous substances, according to the same law, provided that the gases be dry and chemically indifferent to each other, and to the substance of the porous septum. On the other hand, when films of India-rubber or of shellac, moist animal membranes, or even soap-bubbles, are employed as the septa interposed between any two gases, diffusion still takes place, but then not according to the above-mentioned law, but under modifications dependent on the relative solubility of either gas in the interposed septum. Lastly, experiments made by Draper on gases in a state of *solution*, show that these still manifest mutually diffusive tendencies, although not according to Graham's law of their simple diffusion in a dry state. This moist diffusion of gases has been termed *false gaseous diffusion.*

Both *simple* and *spurious* diffusion occur in aerial respiration performed by lungs or air-sacs, but the latter only, in aquatic respiration, performed by gills or moist surfaces.

The breathing air in calm respiration, about 20 cubic inches, amounts to only $\frac{1}{9}$th of the reserve and residual air together, 180 cubic inches, which are ordinarily retained in the lungs (see p. 819). Even in active respiration, it would only amount to about $\frac{1}{4}$th, viz., 45 cubic inches. Hence, so small a displacement of the air in the lungs, at each inspiration and expiration, cannot directly influence the air contained in the remote air-cells, especially as the bronchial tubes constantly increase in their total capacity, from the trachea to the air-sacs. The simple diffusion of gases here comes into play; for since, as we shall presently see, the last portion of air expelled in a long expiration is richer in carbonic acid than the first portion, it is probable that the residual air, which is never expelled from the lungs, becomes increasingly richer in carbonic acid gas, and therefore poorer in oxygen, in the direction of the air-cells; hence the diffusion of oxygen must take place from the larger bronchi, to which the pure air gains access, towards the air-cells; whilst carbonic acid diffuses itself in the opposite direction, from the air-cells towards the larger air-tubes. The respiratory movements doubtless continually change the air in the lungs, and, as it were, partially ventilate the air-passages; but the energy and rapidity of the diffusive process, and its incessant operation, supplement their effects. The diffusive process is accelerated by differences of temperature between any two gases, a condition constantly operating in respiration. Moreover, the pulmonary exhalation, which, in the air-cells and smaller air-tubes, exists in the form of vapor, likewise has a similar tendency to diffuse into the drier air in the larger passages. That this diffusion of carbonic acid gas actually occurs in the lungs, may be shown by steadily holding the breath, with the open mouth kept in communication with a bag, or other reservoir, holding a known volume of atmospheric air, when this latter is soon found to contain a readily appreciable quantity of carbonic acid. In apparent death or trance, when the respiratory movements are suspended, a minimum respiratory interchange of gases may thus take place, just sufficient to prevent the extinction of life. In the deepest stages of hibernation in animals, this also must be the mode of respiration. Under ordinary circumstances, however, the necessity for air cannot thus be relieved; but successive respiratory movements are excited through the nervous system, in order to satisfy it.

But the entrance of oxygen into, and the escape of carbonic acid from, the blood of the pulmonary capillaries, from and into the air in the air-cells, is not explicable by simple diffusion: for this double process is one of *moist* or false gaseous *diffusion.* Both gases must be dissolved as they pass in, or out of, the pulmonary tissues and capillaries; and the actual diffusion result depends, first, on the relative solubility of the diffusing gases in the fluid of the natural moist septum through which they pass, and secondly, on the special chemical affinities of those gases for the blood. The simple diffusion volumes of dry oxygen and carbonic acid, are in the proportion of 1174 to 1000, the oxygen, or lighter gas, having a higher diffusion volume than the carbonic acid or heavier one. But this proportion does not agree with the ratio of the oxygen absorbed to the carbonic acid evolved in respiration, which, according to the Table in p. 823, is as 1255 to 1000. The quantity of oxygen absorbed is, therefore, not only greater than that of the carbonic acid evolved, but greater than that which the law of the diffusion of dry gases would account for. Again, the relative solubility of these gases in the *water* of the walls of the air-cells and capillaries, and in that of the blood, will not explain the difference; for carbonic acid is nearly 30 times more soluble in water than oxygen, and, accordingly, it exhibits a far greater diffusibility through a dead moist membrane, instead of a less diffusibility, as occurs in actual respiration. It has been shown that recent blood, even at a temperature of 32°, retains from 16.8 to 19.8 volumes per cent. of oxygen; whilst water, at 60°, dissolves not quite 3 volumes. Furthermore, fresh blood deprived of its fibrin, at a temperature of 48°, absorbs 178 volumes of carbonic acid, whilst water takes up about 90 volumes. Hence, the proportion between the oxygen absorbed, and the carbonic acid exhaled from the blood in respiration, does not depend on the relative solvent power of the blood for those two gases, which is about as 1 to 10.

The remarkable affinity of blood for oxygen is also shown by another calculation. The absolute quantity of carbonic acid which is taken up by the blood, is larger than that of the oxygen. But in comparison with water, the special affinity of blood for oxygen is much stronger than that for carbonic acid; for the quantity of oxygen absorbed by the blood, in comparison with that absorbed by water, is about as 18 to 3, or 6 to 1, whilst the quantity of carbonic acid absorbed by the blood, in proportion to that taken up by water, is only about as 178 to 90, or less than 2 to 1.

The total quantity of all the gases normally contained in 100 volumes of blood, amounts to somewhat less than 50 volumes, *i. e.*, about half its own volume. This is less than it is capable of dissolving under artificial pressure, or through other means. Of these 50 volumes, about 12.5 are oxygen, 34.5 carbonic acid, and 3 nitrogen. Of 100 volumes of these mixed gases, the mean of several observations, however, gives 28.2 oxygen, 64.7 carbonic acid, and 7.1 nitrogen. Nitrogen, therefore, is also absorbed by blood in larger proportion than by water, which can only take up 1.5 volumes, whilst blood can be made to absorb 5 volumes per cent.

It is plain, that both oxygen and carbonic acid are held in the blood, not merely by its solvent power, as was supposed from the experiments of Magnus, because he obtained those gases from the blood, by placing it under an air-pump, or by displacing them with streams of hydrogen; but that it is in part, and in great part, held in it by special chemical affinities. It is, moreover, evident that the absorption of oxygen by the blood, depends on one kind of chemical affinity, and that of carbonic acid, on another.

The *oxygen* is supposed almost entirely to enter into chemical combination, essentially with some constituent of the red corpuscles; for although, as shown by its relative effects on dark clots, the serum may contain variable quantities of oxygen, yet neither it nor the liquor sanguinis, can absorb more oxygen than pure water. (Berzelius.) That the oxygen is chemically combined is, moreover, inferred from the fact, that pyrogallic acid, which has an extraordinary affinity for this gas, does not withdraw it, when injected in solution into the blood, but appears unaltered in the urine. The extreme affinity of blood for *carbonic acid*, though partly due to the solubility of that gas in water, may be partly owing to some special absorptive power in the albuminoid or other organic constituents; but it is in a marked degree dependent on the carbonate, or perhaps rather on the phosphate of soda, which exists in considerable quantities in the liquor sanguinis.

The special affinity of the red corpuscles for oxygen, has been attributed to the iron contained in them, that element being supposed to be in the condition of a sesquioxide in the corpuscles of arterial blood, and of a carbonate of a protoxide in those of venous blood, the oxygen, it is said, being displaced by the carbonic acid, which preponderates in venous blood, and is the source of the carbonate above mentioned. (Liebig.) It has, indeed, been alleged that the fibrin is concerned in this transportation of the oxygen through the circulation, it having been supposed to be in a higher state of oxidation in arterial than in venous blood. But the spectrum analysis of the blood, proving that oxygen produces such remarkable changes in the relations of the cruorin to luminous rays, would lead to the conclusion, that it is this coloring substance of the red corpuscles, which is the real carrier of oxygen through the blood. Furthermore, it has been shown that the blood corpuscles even absorb ozone, which is oxygen in a peculiar condition, with great avidity, and yield it up to oxidizable substances when brought into contact with them; the cruorin is also specially concerned in this reaction. In animals provided with a distinct circulation and red blood, the activity of the respiratory function is closely related to the number and dimensions of the colored corpuscles in the blood; for these are few and large in the Cold-blooded, whilst they are greatly increased in number and diminished in size in the Warm-blooded Vertebrata. The latter arrangement provides for an enormous multiplication of the surfaces of the corpuscles.

The entrance of oxygen into the blood being thus due to the joint action of false gaseous diffusion and chemical affinity, the *escape of carbonic acid* gas from the blood, is perhaps dependent on diffusion only. The accumulation of this gas in the venous blood, owing to chemical processes to be presently mentioned, produces a greater tension in the carbonic acid in the blood, than in that present in the air of the air-cells; for it is proportionally much more abundant in the former than in the latter. Hence, an outward diffusion of the carbonic acid dissolved in the venous blood, through the moist walls of the pulmonary capillaries and air-cells, and its escape into the residual air, at the surface of the lining membrane of the cells. The carbonic acid thus dissolved in the blood is chiefly contained in a state of solution in the liquor sanguinis, the red corpuscles having no special affinity for it. The absorption and evolution of nitrogen in the respiratory process, are accomplished also by moist diffusion.

Two points yet remain for consideration, viz.,—In what *part of the circulation*, and at *the expense of what constituents* of the blood and tissues, does the oxygen absorbed in respiration, become united with carbon, to produce the carbonic acid given off? The answer to these questions constitutes an important part of the *theory of respiration.* Previously to the discovery of oxygen, nitrogen, and carbonic acid, all explanations of the respiratory process were necessarily vague. The earlier physiologists believed that the air—the source, as they deemed it, of the animal spirits—found its way through the lungs, and obtained an entrance, as such, into the so-called *arteries*.

Oxygen, or phlogiston, was discovered by Priestley and Scheele, in 1774. Black had already described what he called *fixed air*, and Rutherford had determined the existence, in air respired by an animal, of a peculiar *gas incapable* of supporting further respiration, or combustion. Lavoisier named the gas first discovered by Priestley and Scheele, *oxygen;* by him, also, the gas described by Rutherford, now more commonly known by the name of *nitrogen*, given to it by Chaptal, from its being contained in nitre, was named *azote* (*a*, not, and *zoe*, life), from its inability to support life, in respiration; lastly, Lavoisier demonstrated that the fixed air of Black, now shown to be produced alike by the action of acids on limestone, by combustion, fermentation, and respiration, contains the element *carbon*. These great discoveries were indeed the commencement of the modern science of Chemistry, and the foundation of all true chemical theory; and Lavoisier himself, in combining and adding to the knowledge of his predecessors, at once applied the results to explain the respiratory process of animal life, and offered to science the first *theory of respiration*.

Lavoisier saw that the oxygen absorbed in respiration, united, in some way and somewhere, with carbon, to produce the carbonic acid evolved; he regarded the process as a sort of *combustion*, and supposed that the combination took place in the lungs, *i. e.*, in the pulmonary capillaries, in which the obvious change from venous to arterial blood occurs; the oxygen was thought to be there immediately transformed into carbonic acid, and then as immediately given off. But later inquiries have shown that this view must undergo modification. It was not known to Lavoisier, that both venous and arterial blood contain these two gases, and that both, therefore, circulate in the two kinds of blood; nor was he aware, that frogs made to respire nitrogen or hydrogen, that is, an atmosphere destitute of oxygen, continue for a time to exhale carbonic acid. The existence of both carbonic acid and oxygen, in solution, in the entire blood, shows that the combination of oxygen with some carbonaceous compound in the venous blood derived from the disintegrated tissues, does not take place in the lungs only; but that this union must occur in some other part of the body. Moreover, if this moist combustion took place entirely in the lungs, those organs should be very much warmer than any other part of the system; but, though some authorities, as already mentioned, maintain that the blood in the left ventricle, just returned from the lungs, is warmer than the blood in the right ventricle, the alleged increase of temperature has never been stated to be more than 2°; whilst equally competent observers testify to an exactly opposite condition, as regards the temperature of the venous and arterial blood, before, and after, it has passed through the lungs.

According to another and more plausible view, the oxygen in the aerated blood, partly dissolved in the serum, but chiefly in loose chemical combination with the colored substance of the red corpuscles, and perhaps with the fibrin, is conveyed in the arterial blood to the systemic capillaries, where a certain loss of oxygen, and a nearly proportionate addition of carbonic acid, occur, the blood then becoming venous. On this supposition, the process of oxidation, or respiratory combustion, takes place not in the lungs, nor in the pulmonary capillaries, but in the system, in or near the systemic capillaries. This opinion is in harmony with the fact, that the arterial blood once having acquired, in passing through the pulmonary capillaries, its special characters, amongst others its bright color, retains that color, and, by presumption, its other qualities also, along the whole arterial system, only losing them as it passes through the systemic capillaries. It is also consistent with other facts, already mentioned, viz., that, whereas arterial blood contains more oxygen than venous blood, venous blood contains more carbonic acid. If, as is asserted, the sugar found in the venous blood in the right side of the heart, is absent in the arterial blood in the left side of that organ, then a small portion of the oxygen absorbed in the lungs, or else some of that previously contained in the blood, must have united with that carbhydrate, and so have given rise to a certain amount of carbonic acid; but by far the larger proportion of the oxygen probably passes on unchanged in the arterial blood-current.

How much of the systemic process of oxidation which then takes place, occurs in the blood of the systemic capillaries, or in the tissues traversed by those vessels, is yet unknown. But there is reason to believe, that it happens in both situations. In the functional activity of *all* the tissues and glands, both secreting and ductless, but especially of the *muscular* and *nervous* tissues, constant nutritive changes are in progress; their life never stands still. Disintegration and renewal are unceasing; and the former always implies retrograde chemical metamorphoses, of which partial or complete oxidation is a characteristic phenomenon. The production of carbonic acid is one of the ultimate results. It is supposed by some, that here a repetition of the false or moist diffusion process may take place, oxygen passing from the blood in the capillaries to the substance of the tissues and glands, whilst carbonic acid passes from them back into the blood. This interchange of the two gases at the systemic capillary circulation, constitutes the *parenchymatous respiration*, which, so far as the blood is concerned, is exactly the reverse of the pulmonary respiration; for in the former, the blood loses oxygen and gains carbonic acid, whilst in the latter, it loses carbonic acid and gains oxygen. This consumption of oxygen especially by the nervous and muscular tissues, and its combination with their substance, are said to explain the so-called *stimulating* effect of oxygen upon those tissues, when they are actively engaged in their special offices in the living economy. The quantity of oxygen consumed, and of carbonic acid evolved, in any given case, are found to be proportioned to the degree of activity of the nervous and muscular structures. The muscles especially, require a large supply of oxygen for their nutrition, but more for their effective action; the blood returning from a muscle at rest, as we have seen, contains 7.5 vols. per cent. of oxygen, but when in exercise, only 1.25 vols.; whereas arterial blood contains 17 vols. The prepared muscles of a frog, of course deprived of circulating blood, continue to absorb oxygen, and to give off carbonic acid, so long as their contractility is manifested. (G. Liebig.) Whether during life, this denutritive oxidation is entirely completed *in* the tissues, and the resulting carbonic acid is then transmitted from them, to the returning systemic blood, or whether some intermediate products of disintegration enter the blood, and are oxidated therein, or, lastly, whether both varieties of this combustive process takes place during the ordinary nutritive changes in the tissues, is not well known. That substances properly belonging to the blood are also oxidated within the systemic capillaries, cannot be denied; they are probably fatty matters and carbhydrates, or their derivatives, introduced into the blood from the food, constituting the so-called *respiratory food;* but it has hitherto been supposed that these are quite as actively oxidized in the lungs, and in the arterial blood-current generally, as in the systemic capillaries. But many have believed, and recent researches appear to show, that although the nutritive processes of the muscular tissue demand oxygen for the removal of disintegrated albuminoid and other materials, yet that in the active contraction of muscle, or in the development of *animal motion*, it is not, as was supposed, the muscular substance which wastes, by being more actively oxidized, but, rather, that some combustible substances in the blood, of the nature of respiratory food, either fatty matters or carbhydrates, then undergo oxidation, that this chemical action yields the carbonic acid formed in the blood of muscles, and that it is at once the source of the motive power exercised by the muscles and of the heat evolved in the system. (See the Section on Animal Dynamics.)

In conclusion, then, it appears that the oxygen taken in during respiration, combines, first, with the tissues during their action and nutrition, especially with the nervous and muscular tissues; secondly, with the partially effete matters of the blood, and, lastly, with the materials of the respiratory food. Hence, the carbonic acid, which is one of the ultimate products of these changes, is derived partly from the disintegrated substance of the tissues, especially the nervous and muscular tissues, and partly from substances merely assimilated into the blood from the food. The oxidation of the respiratory food appears to take place in the blood itself, partly in the lungs, but chiefly in the arterial blood-current, and, during muscular action, largely in the capillaries of the muscles. The oxidation of the substance of the tissues may occur, partly, in the tissues themselves, outside the walls of the systemic capillaries, but partly, also, in the blood itself, into which certain intermediate effete products of disintegration may enter, and there undergo further oxidation, after the manner of the respiratory food.

The second point above suggested for consideration, viz., the *nature of the substances* immediately *oxidized*, must remain at present in obscurity. That they contain carbon is, however, certain. Some of this united with oxygen forms the carbonic acid given off in respiration. They also contain hydrogen, frequently in excess of the quantity of oxygen atomically present in them; and then, by oxidation of this hydrogen, water must be formed in the system. But some carbon and some hydrogen escape perfect oxidation, appearing, combined with nitrogen and a little oxygen, in the urea, uric, and hippuric acids, and other nitrogenous excretory compounds. The sulphur contained in the albuminoid bodies, and the phosphorus present more especially in the phosphuretted fats of the red blood corpuscles and in the gray nervous substance, are likewise oxidized, at the cost of the oxygen taken in by the respiratory process, so as to form sulphuric and phosphoric acids, which appear in combination with alkalies or earthy matters, in the urine. The sulphur may be partly traced in the intermediate formation of taurin in the bile. With regard to the nitrogen contained in the so-called nitrogenous tissues, it is, as already mentioned, almost entirely accounted for, by the urea and uric acid—passing, probably, through intermediate chemical forms, such as creatin, creatinin, sarcin, glycin, allantoin, and others. Minute quantities appear to escape from the blood, as ammonia. The nitrogen exhaled from the lungs, and the small loss of that substance from the epidermis and the intestinal excreta, are not metamorphic, the former being derived from the air swallowed with the ingesta and the saliva, and the latter being contained in non-metamorphosed organized matter. Cholesterin is also a scarcely oxidized excretory hydro-carbon.

The great object, therefore, of the respiratory function is to introduce oxygen into the living animal economy; this oxygen, by giving rise to numerous and incessant chemical changes, stimulates the animal tissues, combines with their substance and with the products of their disintegration, and ultimately converts them, either into crystalloid products, which can be readily excreted from the kidneys or skin, or into a gas—very soluble in water and in the blood—which can be readily displaced from the latter fluid, in the lungs or in other respiratory organs, by the stronger affinity of oxygen itself for a certain constituent of the blood. In accomplishing this, it also combines with certain constituents of the blood, assimilated to it from the respiratory food, and thus forms more of the same displaceable gas.

As an important collateral result, this process of oxidation, due to the respiratory function, produces *animal motion* and *animal heat.* In the Cold-blooded animals, in which respiration is comparatively feeble, and which consume but a small quantity of the carbhydrates, the quantity of force and heat engendered is relatively small; but in the Warm-blooded Vertebrata, much heat and force are manifested, and the quantity of respiratory food consumed, and the activity of the respiration are very great. The quantities of oxygen absorbed and of carbonic acid evolved, are much larger in the latter than in the former animals.

In animals provided with distinct blood and a complete circulation, the immediate effects of the respiratory process take place in that fluid, which is thus purified and rendered fit to maintain life. But the ultimate effect is still largely exerted on the tissues, the blood acting as a vehicle for the respiratory agent and its products. In the lowest members of the animal scale, respiration is equally necessary, and has similar ultimate results; but its effects are direct or immediate upon the tissues.

The relation between the chemical actions of the body and the amount of force and heat developed in it, also the manifestation of nervous power, and the evolution of electricity and light in animals, phenomena in which oxidation, at the expense of the oxygen absorbed in respiration, is likewise necessary, will hereafter require further consideration.

CONDITIONS WHICH MODIFY THE CHEMICAL PROCESSES OF RESPIRATION.

The quantity of oxygen absorbed, and of carbonic acid eliminated, in the respiratory process, is modified by the frequency of the respirations, the number of times the same air is breathed over again, the temperature of the air, its degree of moisture, and its density; also by the conditions of age, sex, exercise, repose, or sleep, by the character and quantity of the food or drink, the period of the day or season, the state of health or disease, and by the use of remedial agents.

In *rapid breathing*, less oxygen is absorbed, and less carbonic acid is given off, at each respiratory movement, as if sufficient time were not allowed for the usual rate of mutual interchange of the two gases. With six respirations per minute, 5.5 per cent. of the expired air has been found to be carbonic acid; with 24 respirations, 3.3 per cent.; and with 96 respirations per minute, only 2.6 per cent. (Vierordt.) But although in slow breathing, more oxygen is absorbed, and more carbonic acid is exhaled at *each respiration*, yet, in a given time, as shown by multiplying the quantity exhaled by the number of respirations, the absolute quantity of the gases absorbed and exhaled, is increased by rapid breathing. In *deep inspirations*, the interchange of gases is said to be proportionally less, when compared with the quantity of air; but the total amount of interchange is greater, because the volume of air inspired and expired, is so much larger. The *last portion of air* expired, in all cases, contains less oxygen and more carbonic acid than the first portion; the former, no doubt, containing air coming from the finest air-tubes, close to the air-cells, in which the actual absorption and exhalation occur.

The relative *purity* or *impurity of the air* likewise affects the result; as when the same air is breathed over and over again, and so becomes more or less charged with carbonic acid. Thus, in an experiment in which 300 cubic inches of air were repeatedly breathed for a period of three minutes, only 9.5 per cent. of carbonic acid was found in it; the total quantity being 28.5 cubic inches, or 9.5 cubic inches per minute. In the same person, with fresh air at each inspiration, the quantity was 32 cubic inches per minute. However often the same air was respired, it was never found to contain more than 10 per cent. of carbonic acid. (Allen and Pepys.) These results are caused by the increasing difficulty offered by the accumulation of carbonic acid in the air of the air-passages, to the escape by moist diffusion, of the carbonic acid from the blood into the air-cells, and to its simple diffusion through the air of the air-passages.

The effect of an *increased temperature* of the air is to diminish, and that of a *lower temperature* is to increase, the quantity of carbonic acid exhaled by the lungs. Between the temperature of 47° and 67°, *i. e.*, with a difference of 20° in the external temperature, a variation has been observed in the quantity of carbonic acid exhaled, of 2.5 cubic inches per minute. (Vierordt.) At very low temperatures, the quantity of carbonic acid exhaled may even be more than twice as great as that given off at very high temperatures. A sudden increase of temperature produces a marked immediate effect, viz., a decrease of 2.75 cubic inches per minute, for 16° of elevation of temperature, but this is not subsequently so regularly maintained. (Dr. E. Smith.) The absorption of oxygen is, of course, inversely affected.

The *density of the air* also influences the chemical changes dependent on respiration, their activity being increased when the density of the air is diminished.

A *moist atmosphere*, the temperature being the same, greatly favors, in animals, the exhalation of carbonic acid; moreover, the influence of moisture is so great as to neutralize, at high temperatures, the effect of such temperatures in diminishing the exhalation of that gas. (Lehmann.) The exact hygrometric state of the air ought always, therefore, to be taken into account, in experiments on the composition of expired air. The great influence of moisture may account for some of the discrepancies between the results of different observers.

As regards *age*, the quantity of oxygen absorbed and of carbonic acid exhaled, increases generally, in both sexes, to about the thirtieth, and then remains stationary to the fortieth year, after which it diminishes, so that at seventy, the amount only slightly exceeds that proper to the age of ten years. The influence of *sex*, as might be expected from the greater size and activity of men, is, after the eighth year, shown in the proportionally larger amount of oxygen absorbed, and of carbonic acid exhaled, in that sex. In the male also, the increase due to age, continues progressively up to the thirtieth year, at which period it is stationary; whereas in the female, the gradual increase stops at the age of puberty, and the quantity remains stationary until about forty, when it once more increases for a time, before the diminution dependent on old age begins. The smaller absolute quantity of carbonic acid exhaled in childhood, is, nevertheless, very large, in proportion to the weight of the body, in accordance with the high activity of the nutritive function, and with the large consumption of food at that period. The *size* of the body, in different adults, produces a correspondent result on the total quantity of carbonic acid exhaled. The development of the muscular system, however, produces a greater effect than that which depends on the mere height or weight of the body, or on the dimensions of the thorax.

Exercise, as might be expected, increases the quantity of carbonic acid exhaled, not only whilst it is being taken, but also for a short time afterwards. The increase may equal one-third of the amount exhaled during rest, and this may continue for one hour after the cessation of exertion. This result depends both on a greater quantity of air being breathed, and on an increased percentage of carbonic acid in the expired air. (Vierordt.) Other observations show even a greater relative increase, for in walking two and three miles per hour, the quantities, 18.1 grs. and 25.8 grs., were about two or two and a half times as great as the normal amount in the sitting posture: at the tread-wheel, the quantity fluctuated between 42.9 grs. and 48.6 grs., that is, from about four and a half to five times as great, the pulse and the respiration being, of course, greatly accelerated. (E. Smith.) Prolonged exertion producing fatigue, diminishes the exhalation. Much less carbonic acid is exhaled during the *night* than in the *day*. During *sleep*, the amount given off is considerably diminished, in correspondence with the more superficial and slower character of the respiratory movements of the chest, with the cessation of the ordinary actions of the muscular and nervous tissues and of the usual metamorphoses of the respiratory food, and with the smaller loss and production of heat. In experiments performed in air-tight chambers, the diminution per hour in sleep, was about one-third of the normal quantity. (Scharling.) According to other estimates, the quantity exhaled, in a given time, during profound sleep, is about one-half that of the average quantity in the same time during the day.

The *period of the day* influences the quantity of carbonic acid exhaled, quite independently of the condition of sleep or wakefulness. The ratio in a like time of the night and day, being as 1 to 1.25 (Scharling), or as 1 to 1.8. (E. Smith.) Taking the whole day of 24 hours, the smallest quantity is exhaled in the middle of the night, and the largest in the middle of the day; a slight increase occurs at sunrise, and a prolonged and constant diminution after 9 o'clock in the evening. (E. Smith.) The difficulty of resisting the effects of severe cold, between midnight and sunrise, is well known. A *seasonal* influence on the products of respiration has also been noticed: the maximum product occurs in spring (April and May), and the minimum at the end of summer (September), a gradual increase occurring in early winter (October, November, and December), and a gradual decrease in early summer (June, July and August). Hence, heat, as the result of seasonal changes, equally with artificial heat, diminishes the quantity of carbonic acid exhaled, and climatic cold increases it; moreover, it was found by Barral, that the daily quantity of carbon exhaled by the skin and lungs, was, in winter, upwards of 5000 grains, and in summer only about 3700 grains. But neither temperature alone, nor this, added to the effects of atmospheric pressure, account for the seasonal changes. (E. Smith.) It may be remarked, however, that the hygrometric condition of the air in the above researches, was not taken into account, but this, as shown by Lehmann, is of the highest importance; the period of increase corresponded with the wet months, and that of decrease with the dry months of the year.

Food generally increases the absolute quantity of carbonic acid given off from the lungs, whilst *fasting* has the opposite effect, the proportion of carbonic acid in a given quantity of the expired air being, however, greater during starvation. Thus, in a person six feet high, in whom the average quantity of carbon exhaled, when at rest, with ordinary diet, was 7.85 oz., the daily quantity exhaled whilst fasting, was 5.9 oz.; the diminution produced by fasting for the 24 hours, being rather more than one-fourth the usual quantity exhaled when taking food. (E. Smith.) The quantity exhaled in fasting, sinks to a certain line, which has been named the *basal line*, below which, in health, it does not descend, but prolonged starvation ultimately diminishes it. The influence of food has been shown, by an increase after breakfast of one-fourth the previous quantity, and after dinner of about two-thirds (Scharling); the chief increase noted by Dr. Smith, was after breakfast and tea, and not after early dinner. Thus, the average quantity of carbonic acid exhaled, by a certain person, being 20.6 cubic inches (9.77 grs.) per minute, the quantity during continuous fasting being about 14 cubic inches (6.61 grs.), and the maximum and minimum quantities in the working day with food, 22 cubic inches (10.43 grs.) and 14.2 cubic inches (6.74 grs.), the increased exhalation after breakfast and tea was from 4.2 to 6.3 cubic inches (from 2 to 3 grains), and after early dinner only from 2.1 to 4.2 cubic inches (from 1 to 2 grains). The different effect of different kinds of food and drink, as observed by Dr. Smith, is, in some respects, remarkable: all nitrogenous foods increase the exhalation of carbonic acid; and so does any mixture of nitrogenous matters with the carbhydrates, such as is found in bread, oatmeal, and milk; but pure starch has scarcely any effect; pure fat seems even to diminish the quantity of carbonic acid evolved, though pure sugar increases it. Tea, coffee, and cocoa cause an increase more sudden and marked than that produced by any other substances experimented with; pure alcohol also increases the quantity; but of the spirits ordinarily in use, rum increases the quantity, brandy and gin diminish it, whilst whiskey varies in its effects; wine and ale increase it, whilst the volatile or aromatic ingredients of both spirits and wine, seem to lessen the quantity exhaled. Distilled water has been found to diminish the exhalation of carbonic acid. The opposite effects of different alcoholic fluids, such *e. g.* as rum and brandy, are referred by Dr. Smith to the separate action of the alcohol, sugar, aromatic substances, and nitrogenous bodies in each of those fluids respectively; and the different effects of weak alcoholic liquors, and of pure alcohol, have been explained by supposing, that in the former case, the alcohol may act chiefly by stimulating the respiratory changes; whilst in the latter, it may interfere with the oxidation of the ordinary constituents of the body. Habitual drinkers usually accumulate fat.

From the preceding facts it would appear that the constituents of food do not act in proportion to the quantity of carbon they contain; but that some specifically excite the respiratory interchanges, apparently by increasing the processes of oxidation in the body, and by augmenting the depth of the respirations, or the quantity of air inspired. Two substances, identical in composition, sugar and starch, act differently; the former exciting respiratory interchange, the latter not doing so. Milk, especially when new, is a more powerful excitant even than a purely albuminoid substance. The nitrogenous foods increase the quantity from 1 to 2.1 cubic inches (from ½ to 1 gr.), mixed nitrogenous and hydrocarbonaceous foods give an increase of about 4.2 cubic inches (2 grs.) per minute; milk, a perfect mixed diet, 4 cubic inches (nearly 2 grs.) per minute; spirits of wine 2.1 cubic inches (1 gr.); rum 3 cubic inches (about 1½ gr.); ale and stout 2.1 cubic inches (1 gr.); whilst tea, coffee, and cocoa increase the evolution of carbonic acid from 3 to 6.3 cubic inches (1½ to 3 grs.) per minute. (E. Smith.) Certain substances, such as sugar, alcoholic fluids, tea, and coffee, produce their effect very quickly, reaching their maximum within half an hour; whilst flesh, bread, oatmeal, and milk act later, their influence enduring as long as two hours and a half. (E. Smith.) Lastly, the effect of a high diet on one day, may affect the respiratory changes, as well as the excretion of urea, on the following day, imparting, as it were, a somewhat durable stimulus to the system.

The amount of carbonic acid exhaled is diminished in all chronic and organic diseases of the lungs, in hectic conditions, and in cholera; whilst it is increased in chlorosis, in which the number of the red corpuscles is diminished. The proportion of carbonic acid in a given amount of expired air is increased in certain exanthematous diseases, as in measles, and especially in small-pox, in which it is nearly doubled; whilst, on the other hand, it is reduced about one-half in typhus fever. The absolute quantities exhaled in these and other diseases, have not been sufficiently investigated.

The effects of remedial agents, generally, on the absorption of oxygen and exhalation of carbonic acid, have likewise yet to be scientifically determined. The inhalation of the vapor of chloroform and ether diminishes remarkably the escape of carbonic acid from the blood; and this constitutes an accessory cause affecting the nervous system. In the treatment of diseases by change of climate, the increased respiratory interchange which is induced by cold, and the diminished oxidation which takes place in higher temperatures, should be considered, as well as the great influence of atmospheric moisture, in increasing the exhalation of carbonic acid, and of a dry air in diminishing it. It is possible that, in some degree, the hygienic value of a dry climate, such as Egypt, in the treatment of diseases of exhaustion, may depend upon the comparatively limited amount of waste and oxidation of the tissues generally.

In hibernating animals, the quantity of oxygen absorbed and carbonic acid evolved is, like the respiratory movements themselves, reduced to a minimum, or, it is said, the respiratory interchanges are even absolutely arrested.

Effects of Breathing other Gases than Air.

As already mentioned, many gases and vapors of volatile substances are introduced into the system by absorption from the pulmonary mucous membrane. Chloroform, ether, camphor, and turpentine, thus produce their characteristic active results on the system; so likewise do tobacco smoke, the smoke of the datura stramonium, and the vapor of mercury. The gaseous combinations of hydrogen, with other elements, such as arseniuretted, phosphuretted, sulphuretted, and carburetted hydrogen, are especially and directly poisonous. The arseniuretted hydrogen is the most powerful, less than one-tenth of a grain, when inhaled, having proved fatal to Man. Sulphuretted hydrogen stands next in potency, air containing from one to three per cent. having been respired without much inconvenience to Man, though much less destroys animals. Carburetted hydrogen, or marsh-gas, the fire-damp found in coal mines, is still less active as a poison, but destroys life when present in large proportions. The vapors of nitric, nitrous, sulphurous, and hydrochloric acids, as well as those of ammonia, which are compound bodies, and those of bromine, iodine, and chlorine, which are simple bodies, are likewise positively injurious when inhaled into the lungs, causing direct irritation of the mucous membrane, and producing decompositions of a special kind when taken into the blood. Besides causing an increase of the mucous secretion, intense bronchorrhœa, serous inflammation, and often permanent cough, they frequently produce, through reflex nervous action, violent spasm of the glottis, and so may cause *asphyxia* or death from *suffocation*, without entering the air-tubes; sometimes death results from œdema of the glottis. There is one gas, a compound of nitrogen with oxygen, the nitric oxide, or *laughing gas*, which, when inhaled for some minutes, produces a state of temporary intoxication, and, at the same time, maintains respiratory chemical changes at the expense of the oxygen contained in it, the products of respiration being, in such a case, carbonic acid with a large excess of nitrogen. By a long continuance of the experiment, insensibility, and, as has been shown on animals, actual suffocation, probably from the carbonic acid, may be produced.

Besides these directly irritant and poisonous gases, there are some which are only indirectly injurious, being in themselves inert and innocuous. Thus, snails have been kept in pure *hydrogen* for a long time, and frogs as long as fourteen hours, without any injurious effects; and *nitrogen* is equally harmless to frogs. (Collard de Martigny, Müller, Bergmann.) In the experiments on frogs, carbonic acid is exhaled, for a time, in as great, or even greater quantity, than if the animals had breathed atmospheric air; more is excreted in hydrogen than in nitrogen. The total quantity of carbonic acid, so given off, is, however, limited, doubtless because no more oxygen can be absorbed; the lungs of the frog have been usually emptied of air, by compression, or the use of the air-pump, and the only oxygen left in the animal was that in the blood or the tissues. Some of the hydrogen and nitrogen seems to be absorbed, but only in small quantity. The exhalation of carbonic acid, in these cases, must be owing to the successive moist and dry diffusion taking place into the hydrogen or nitrogen; and the diffusive force, in the former gas especially, would be much greater than that into air. In the case of Warm-blooded animals, only the newly-born, or very young, can support such an experiment without the rapid extinction of life; but they may live a short time and yield carbonic acid to the artificial atmosphere of hydrogen or nitrogen. Fully-grown Birds and Mammalia expire rapidly in pure hydrogen or nitrogen; the symptoms being instantaneous difficulty of respiration, gasping, loss of muscular power, and, at the end of two or three minutes, cessation of the heart's action; the lungs are found engorged with venous blood. The animals, indeed, are asphyxiated from the deprivation of oxygen, of which they require a larger and more constant supply, in comparison with the young of the same species, or with Cold-blooded animals. That the nitrogen is not in itself injurious, is obvious from the large proportion of it—about four-fifths—in ordinary atmospheric air; and that the same is true of hydrogen, is shown by the fact that, if this gas be mixed with oxygen in the same proportions as nitrogen and oxygen exist in the air, animals live and breathe in such a mixture without the least inconvenience.

From all that has preceded it is evident, that of the two gases in the atmosphere, the oxygen is the active ingredient in respiration; for nitrogen alone, as we have seen, causes suffocation. Hence *oxygen* has been named *vital air*. Considered in reference to its office, it is a supporter of *life*, or of the proper animal functions; but, as regards the *body* itself, it is a destructive, not a constructive, agent, operating constantly in its disintegration and oxidation, in the various processes of animal life. The proper medium for healthy respiration is pure atmospheric air, which contains, besides a minute trace of carbonic acid, four-fifths of nitrogen, and only one-fifth of oxygen. But an addition to the normal quantity of oxygen is of more or less importance. Twice or three times the usual quantity in air, at first, causes no apparent inconvenience, and no special change in the products of respiration; but it is probable that, after a time, certain injurious consequences would ensue, though experiments are wanting to determine the point. Pure oxygen, however, is highly injurious; the vital functions are stimulated as if by a fever; the pulse and respiration are increased in frequency; after an hour, insensibility gradually comes on, complete coma then ensues, and death occurs in from six to twelve hours. On examination of the animal, the heart is found pulsating violently, although the motion of the diaphragm is arrested. The blood, after death, is of a bright color in the veins, as well as in the arteries; the mucous membranes are red; the blood coagulates quickly; oxygen has evidently been absorbed in large quantity; the blood in the systemic capillaries is no longer properly changed to venous blood; and, on the other hand, the presence of over-oxygenated blood in the nervous centres which govern respiration, lessens their activity, which is called into play apparently by the stimulus of a certain quantity of carbonic acid in the blood. The symptoms produced by breathing oxygen, are rapidly alleviated by respiration in atmospheric air.

Of the three compound gases containing carbon, viz., carburetted hydrogen CH_4, carbonic oxide CO, and carbonic acid CO_2, *carbonic oxide* is the most poisonous. This gas, which is produced by the imperfect combustion of carbon, is given off, together with carbonic acid, in the fumes of burning coke or charcoal. The addition of 5 per cent. of this gas to air, is sufficient to make it irrespirable, and to cause death; and it is this gas, rather than the carbonic acid, which produces fatal results in suicide by charcoal fumes. In these fumes, however, besides the carbonic acid and the carbonic oxide, there are ammoniacal salts, an empyreumatic oil, sometimes sulphurous acid, watery vapor, nitrogen, and traces of free oxygen. The symptoms produced by smaller quantities of carbonic oxide in air, are, giddiness, faintness, headache, convulsions, and irregularity of the pulse; the freest inspirations, or insufflations of pure air, or of diluted oxygen, are essential for recovery at such a crisis. When death ensues from the breathing of carbonic oxide, the blood is not found dark, as in asphyxia from carbonic acid, but even the venous blood is of a bright red hue, and the properties of the corpuscles are permanently modified; for they exhibit no further changes on exposure to oxygen or to carbonic acid.

Carbonic acid being a natural product of the respiratory process, its injurious effects upon animal life possess an interest greater than that which attaches to those of other gases. The quantity of this gas in ordinary air is about 4 parts in 10,000, $\frac{1}{2500}$th part, or .04 per cent. In air once breathed, the proportion rises to about 4 per cent, *i. e.*, $\frac{1}{25}$th part, or 400 parts in 10,000, a corresponding quantity of oxygen being simultaneously removed. If this air be respired a second time, a much smaller portion of carbonic acid is added to it, and still less at each subsequent respiration. When air contains about 10 per cent., or $\frac{1}{10}$th its volume of carbonic acid, when one-half of the normal quantity of oxygen has likewise disappeared, it is irrespirable, and fatal to man. Warm-blooded animals have been found to die in an atmosphere containing from 12 to 18 per cent. The symptoms of poisoning may be said to begin with even a much smaller proportion in the air, even with as little as one-third per cent. For a time no marked symptoms are observed, but after a certain interval there occur headache, sense of fulness in the temples and occiput, giddiness, muscular prostration, oppression of the chest, difficult respiration, palpitation of the heart, subjective, disturbed sensations, such as singing noises in the ears, and flashes of light, faintness, delirium, then drowsiness, unconsciousness, convulsions, coma, and death. Sometimes vomiting occurs, and occasionally death ensues from apoplexy. On examination, after death, the cerebral vessels are found congested, and serous exudations to be present in the ventricles and at the base of the brain; sometimes clots of blood are found in the substance of the brain. Carbonic acid is the choke-damp of mines.

Asphyxia.

When a person is completely immersed in an atmosphere of almost *pure carbonic acid*, as in brewers' vats, in cellars in which wine is fermented, or in caverns, such as the Grotto del Cane, death occurs much more rapidly; the glottis is sometimes spasmodically closed, and respiration is as completely arrested by this impediment to the passage of air, as it is in strangulation, or in any other mechanical form of suffocation. Even if the glottis should remain patent, the entire absence of oxygen from such an atmosphere, would produce suffocation almost as speedily; for twenty seconds is the extreme time during which the breath can be held by voluntary effort; so that suffocation might be said to commence at the expiration of that brief period. In any case, the form of death, which so rapidly ensues, is that by *asphyxia*, the essential characters of which are, loss of muscular power and consciousness, cessation of the movements of the chest, and then of the pulsations of the heart, with accumulation of blood in the right side of that organ, and in the whole venous system, so that even the skin becomes livid. The blood remains a long time fluid.

The mode in which death occurs from asphyxia, whether caused by compression of the chest and abdomen, by direct suffocation from external strangulation, internal choking, or spasmodic closure of the glottis, or whether produced indirectly by immersion in some irrespirable gas, or in water, by paralysis of the respiratory nervous centres, or by narcotic poisonings, is somewhat complicated. The respiratory interchanges of carbonic acid and oxygen, between the blood in the pulmonary capillaries and the air in the air-cells, diminish or cease; the venous blood, reaching the lungs, no longer gives off its carbonic acid, and the pulmonary capillary circulation is more or less quickly stopped. The *forward* effects of this are, that the left side of the heart receives, at first, imperfectly aerated blood, and then little or no blood at all, so that the functions of the brain and nervous centres, of the muscular system, and of the heart itself, all of which require, for their maintenance, a due supply of arterial blood, gradually or rapidly cease; ultimately, the left side of the heart and the arteries, accommodating themselves by their muscular contractility and elasticity, are nearly or entirely emptied, or contain but very small quantities of dark non-aerated blood. On the other hand, the *backward* effects of the arrested circulation in the pulmonary capillaries, are ultimately to distend the right side of the heart, and the entire venous system, with very dark blood. The stagnation of the blood in the pulmonary capillaries, which is the first stage of the fatal process, has been attributed to some direct influence of the carbonic acid on the blood corpuscles;

for the circulation in the transparent parts of animals may be arrested by subjecting the capillaries to the action of carbonic acid; moreover, as the red corpuscles of the blood undergo enlargement when acted upon by this gas, it has been supposed that these bodies may then obstruct the capillaries mechanically. (Wharton Jones.) It has also been suggested that there exist, in the healthy state, certain local attractions and repulsions between the walls of the pulmonary capillaries and the currents of the non-aerated and the aerated blood respectively, connected with the respiratory interchanges of the carbonic acid and oxygen, which are essential to the onward movement of the blood-current.

In the slower forms of asphyxia, indicated by the more gradually developed cerebral symptoms, the stagnation of the blood in the pulmonary capillaries is preceded by a simple retardation of the blood-current in them; but the entire blood is defectively aerated. Hence this fluid, owing to its abnormal condition, passes imperfectly through the systemic capillaries; the arteries and the left ventricle become somewhat distended; and the heart for a time beats more powerfully and more frequently, as if to overcome this resistance. But the activity of the nervous centres and muscular system is soon diminished, in proportion as the blood becomes less and less aerated; at length, both are completely paralyzed, the senses fail, consciousness is lost, the respiratory nervous centres lose their power, respiration becomes labored and much interrupted, general convulsions ensue, and respiration ceases. The contractile power of the heart itself, becoming diminished, it beats more slowly, and at length ceases to contract. The left ventricle not only no longer receives its appropriate stimulating blood, but even loses its power of rhythmic contraction, owing to the poisoning of the blood in the nutrient vessels of the heart and its nervous ganglia; whilst the cessation of the action of the right ventricle is chiefly the result of over-distension, for venous blood is its proper stimulus, and the contractility of that side of the heart is retained, for more or less time, after it has ceased to beat spontaneously. If, indeed, the state of over-distension be relieved by puncturing the right auricle or the great veins, the right ventricle will again begin to contract; whilst the left ventricle may be once more excited by duly arterialized blood. By some, it has been supposed that the obstruction to the pulmonary capillary circulation, is due to the mechanical non-expansion of the lungs, but it also occurs in asphyxia produced in animals made to respire nitrogen, in which case, the lungs are not contracted. Moreover, the vascular pulmonary obstruction which is caused by asphyxia, is relieved by the inhalation of oxygen, very rapidly, as compared with the gradual dilatation of the arterial system, when any mechanical obstruction to the circulation of the blood in them, has to be removed. The question has arisen, whether in asphyxia from the inhalation of carbonic acid, the result is due to the diminished supply of oxygen, or to a directly poisonous effect of the carbonic acid itself. The latter conclusion is supported by the fact that when animals are made to breathe an atmosphere consisting of carbonic acid, mixed with oxygen in the same proportion as exists in air, or even in much greater proportion, they are still quickly destroyed by asphyxia. It has been found, moreover, that a diminution in the proportion of oxygen, increases the poisonous effects of the carbonic acid; where the quantity of oxygen is reduced to 16 or 10½ per cent., death speedily ensues, even though the carbonic acid is constantly being removed; but if the oxygen be maintained at its ordinary proportion of 21 per cent., the ill effects of carbonic acid are not manifested more rapidly, even though as much as 20 per cent. of that gas be present in the respired air. A still more positive proof of the directly poisonous influence of carbonic acid, is furnished by the following singular experiment. One bronchus of a tortoise was tied, and the animal lived apparently without inconvenience; the respiration, accomplished by one lung, being temporarily sufficient. But if, by special arrangements, ordinary air was allowed to enter one lung, and carbonic acid the other, through their respective bronchi, the animal soon died, the introduction of carbonic acid into the system being the sole difference in the two conditions. This experiment also proves that carbonic acid may, in certain conditions, not only not escape from the lungs, but may actually be absorbed by them. (Rolando.)

Suspended Respiration and Animation.

The length of time which different animals, or Man, can survive without respiration, varies, according to many conditions, chiefly referable to the relative degree of activity of the animal functions in any given case, but sometimes also to special provisions. The more active the nutritive and respiratory processes, and the greater the development of heat, the sooner does death by suffocation ensue. Thus, cold-blooded animals, with the feebler activity of all their functions, have less need for air than warm-blooded animals, the water-newt, *e. g.*, frequently remaining, even in its active summer life, a quarter of an hour or more under water; whilst frogs and lizards have been kept, in experiments, for years without food, inclosed in porous stones, or buried in earth; but when they are hermetically inclosed, they sooner or later die. Warm-blooded animals and Man, on the other hand, are rapidly asphyxiated. Hibernating Mammalia are able to live, in their peculiar torpid condition, with a supply of air so defective, that they would die asphyxiated in it, during their active summer condition. Newly-born animals, being less dependent on the perfect state of respiration, survive submersion for much longer periods, especially when their temperature is low; rabbits, under such circumstances, having survived as long as 26 minutes, and puppies even 50 minutes; young guinea-pigs, however, do not seem to possess this immunity. Even full-grown animals resist the injurious effects of submersion in water, for a longer time than usual, when their temperature has been previously reduced as low as 64°, but not lower. (Brown-Séquard.) Again, it has been observed, that full-grown warm-blooded animals die sooner from drowning, than from simple apnœa caused by immersion in nitrogen or hydrogen, by choking, or by strangulation, the more rapid fatal result in drowning, being due, not only to the deprivation of air, but to the partial filling of the air-passages and air-cells with water, and to the poisonous effects of carbonic acid. Thus, the average time in which rabbits, suddenly deprived of air, cease apparently to live, has been found to be 3 min. 25 sec.; in the case of dogs, the time is 4 min. 5 sec.; the action of the heart, however, was maintained for 7 min. 10 sec.; moreover, the animals thus deprived of air, could be restored to life after 3 min. 50 sec. On the other hand, an immersion in water for only $1\frac{1}{2}$ or 2 minutes, usually rendered recovery impossible. Lastly, if the trachea of an animal be divided and plugged, so that the water may be excluded from the air-passages, and it be then submerged, even for four minutes, it may recover its respiratory power (Rep. Med. Chir. Soc.). Animals subjected to a diminished atmospheric pressure under the receiver of an air-pump, are asphyxiated, sometimes, perhaps, owing to the liberation of gases in the blood of the small pulmonary bloodvessels.

In a few Warm-blooded Mammalia, destined for an aquatic life, as, *e. g.*, in the Cetacea, there exist special provisions in the presence of arterial and venous plexuses or diverticula, in which the blood may accumulate during their submergence. The retia mirabilia, or wonderful network of the arteries, contain a supply of oxygenated blood, which is employed, as required, by the submerged animal; whilst the large venous plexuses receive a like quantity of deoxygenated blood. Whales can remain upwards of an hour beneath the water. Certain diving birds possess similar diverticula of both arteries and veins.

In Man, under ordinary circumstances, the breath can be held for about 20 seconds; but after an ordinary inspiration, the period of indurance without air may be prolonged to 25 seconds. If, however, a single forcible expiration be made, and then a deep inspiration be taken, the period may be extended to about 33 seconds. If five or six deep expirations and inspirations be made, one after the other, so as to clear the lungs as completely as possible of used-up air, and then a deep inspiration be taken, from one and a half to two minutes may be allowed to pass without inconvenience from want of air, with the exception of slight giddiness at first. This fact it is useful to remember in passing through rooms filled with smoke or on fire, or on entering such rooms, or descending a vat, or diving in water to save the life of another. In entering an apartment on fire, or filled with smoke, it is better to stoop or creep along the floor, as the air in that situation is cooler and less pungent; but in the case of wells, brewers' vats, or sewers, the entrance of which, for a time, is most hazardous, there is no great elevation of temperature, and the lower strata of air are the most poisonous. By practice, persons may accustom themselves to an interruption of the respiratory process for three or four minutes, without loss of consciousness, or other serious consequences, three minutes being the ordinary limit attained by the skilled pearl-divers of Ceylon.

Some of these divers use a small *spring-clip*, made of horn, which they slip over the end of the nose, the instant before they enter the water. This, on the one hand, prevents the escape of air from the thorax through the nose, and, on the other, the entrance of water through the same passage; without this contrivance, the diver must hold the nose with one hand, which would limit his powers of search and prehension at the bottom of the sea; moreover, if the nostrils are not closed, the muscles of the glottis and of inspiration must be kept incessantly strained, or an irresistible expiratory effort would take place, and expel some air from the chest. With this protection on the nose, however, the diver has only to keep the mouth closed; the inspiratory muscles are not required to act, and the contents of the chest are mechanically retained.

Persons who have been submerged for four or five minutes are rarely restored to life, and sometimes, often owing, doubtlessly, to the entrance of water into the air-passages, persons who have been submerged scarcely a minute cannot be resuscitated.

A submergence of five minutes is almost certainly fatal to Man, still recoveries have occasionally taken place after much longer periods, even a quarter of an hour, and it is said after half an hour or more. In such cases, however, it is believed that just before, or at the moment of immersion, *syncope*, from some cause or other, has taken place. In this condition, or in a state of *trance*, the heart beats feebly, or scarcely at all, the respirations are weak and shallow, and life may be said to be interrupted, or so feebly maintained that it may be continued as well under the water as above it; venous blood is not propelled through the system, so that the nervous centres are not poisoned by carbonic acid; and, unless the temperature of the water be very low, the vitality of the respiratory nervous centres, of the muscles of respiration, and especially of the heart, may be suspended, but not altogether destroyed. Such a condition of syncope or fainting may be produced, either by a severe blow causing concussion of the brain, by other physical shocks to the body, by sudden fright, or violent passion. For these reasons, attempts at the resuscitation of apparently drowned persons should always be resolutely persevered in, even under most unfavorable circumstances.

Certain methodical rules have been laid down, by means of so-called *artificial respiration*, for the recovery of drowned persons; and, with the exception of such parts of those rules as relate to the removal of water from the mouth and nostrils, and the replacing of cold and wet, by warm dry clothing, similar instructions would apply to the recovery of persons suffocated in brewers' vats, wells, and sewers, and also to those asphyxiated in the administration of ether or chloroform. In the case of persons mechanically strangled or choked, the external or internal cause of obstruction in the air-passages must, of course, be first removed. The earlier rules, published by the Royal Humane Society, for the recovery of drowning persons, were improved by Dr. Marshall Hall; but the most simple and convenient are those of Dr. Silvester, which have been incorporated with the present rules of that society.

Rules of the Royal Humane Society.

Treatment to Restore Natural Breathing.

Rule 1.—*To maintain a Free Entrance of Air into the Windpipe.*—Cleanse the mouth and nostrils; open the mouth; draw forward the patient's tongue, and keep it forward: an elastic band over the tongue and under the chin will answer this purpose. Remove all tight clothing from about the neck and chest.

Rule 2.—*To adjust the Patient's Position.*—Place the patient on his back on a flat surface, inclined a little from the feet upwards; raise and support the head and shoulders on a small firm cushion or folded article of dress placed under the shoulder-blades.

Rule 3.—*To imitate the Movements of Breathing.*—Grasp the patient's arms just above the elbows, and draw the arms gently and steadily upwards, until they meet above the head (this is for the purpose of drawing air into the lungs); and keep the arms in that position for two seconds. Then turn down the patient's arms, and press them gently and firmly for two seconds against the sides of the chest (this is with the object of pressing air out of the lungs. Pressure on the breast-bone will aid this). (The Silvester method.)

Repeat these measures alternately, deliberately, and perseveringly, fifteen times in a minute, until a spontaneous effort to respire is perceived, immediately upon which cease to imitate the movements of breathing, and proceed to Induce Circulation and Warmth.

Should a warm bath be procurable, the body may be placed in it up to the neck, continuing to imitate the movements of breathing. Raise the body in twenty seconds in a sitting position, and dash cold water against the chest and face, and pass ammonia under the nose. The Patient should not be kept in the warm bath longer than five or six minutes.

Rule 4.—*To excite Inspiration.*—During the employment of the above method, excite the nostrils with snuff or smelling-salts, or tickle the throat with a feather. Rub the chest and face briskly, and dash cold and hot water alternately on them.

Treatment after Natural Breathing has been Restored.

Rule 5.—*To induce Circulation and Warmth.*—Wrap the patient in dry blankets, and commence rubbing the limbs upwards, firmly and energetically. The friction must be continued under the blankets, or over the dry clothing.

Promote the warmth of the body by the application of hot flannels, bottles or bladders of hot water, heated bricks, &c., to the pit of the stomach, the armpits, between the thighs, and to the soles of the feet. Warm clothing may generally be obtained from by-standers.

On the restoration of life, when the power of swallowing has returned, a teaspoonful of warm water, small quantities of wine, warm brandy and water, or coffee should be given. The patient should be kept in bed, and a disposition to sleep encouraged. During reaction, large mustard plasters to the chest and below the shoulders will greatly relieve the distressed breathing.

In the recovery from *drowning*, or from other forms of *asphyxia*, the various phenomena which characterize the production of that state are, as it were, reversed or undone, beginning at the re-establishment of the flow of blood through the pulmonary capillaries. On the introduction of air into the lungs, by the artificial imitation of the respiratory movements, oxygen is once more absorbed by, and carbonic acid given off from, the venous blood reaching those organs; these renewed chemical changes in the blood, induce again its onward motion through the capillaries into the pulmonary veins; thence it flows on, more or less oxygenated, into the left side of the heart, which resumes contractions of sufficient strength to propel this oxygenated blood into the nutrient arteries of the heart and its ganglia, as well as into the muscular and nervous systems generally. In this way, the rhythmic power of the heart itself, and the excitability of the respiratory nerves, the nervous centres, and muscles, are restored, and, subsequently, conscious sensation, perception, and volition. In the meantime, moreover, the respiration of the capillary circulation in the lungs, liberates the blood previously pent up in the right cavities of the heart, gradually unloads those cavities, facilitates more and more, at each moment, their free action, and so, by degrees, empties the over-distended venous system. The freer return of the blood from the systemic capillaries being thus permitted, that part of the circulation also is relieved, the lividity and coldness of the surface of the body are removed, and simultaneously, the vigor of the left side of the heart being increased, the flow of properly oxygenated blood throughout the whole system, and life itself, is restored. The action of the air upon the blood in the capillaries of the skin, may slightly assist in these favorable changes; for the lividity of the skin sometimes diminishes, even when life is not restored.

It has been found by Dr. Richardson, that artificial respiration, by direct inflation of the lungs of animals, fails to restore the pulmonary capillary circulation, if the beats of the heart have actually ceased, an event which usually occurs after five minutes. Insufflation of the lungs with hot air, is more stimulating to the heart, but yet not adequate to restore the pulmonary blood-current. The employment even of oxygen or ozone, mixed with the air, is useless, unless the heart is still acting. Galvanism will revive the respiratory movements, but, unless the heart is still beating, it fails to re-establish the motion of the blood through the lungs. In short, if once the blood-current in the pulmonary artery and its branches be interrupted, the blood corpuscles in the small vessels speedily coalesce, and then the increasingly feebler contractions of the heart merely propel blood into the trunk of the pulmonary artery, but not through the lungs. Artificial respiration by insufflation, or even by Silvester's method, must not be attempted, or continued, when the feeblest natural respiratory movements are discernible. The introduction of air into the lungs must then be very gentle; the temperature of the air should, if possible, be as high as 120°, and never below 60°. Galvanism, being exhaustive of, as well as stimulating to the respiratory muscles, should either be employed for a limited time, or should be perhaps avoided. Certain experiments, on what Dr. Richardson terms *artificial circulation*, encourage him to hope, that means may ultimately be found of restoring life, if the blood is not actually coagulated, an event which does not usually take place before twenty minutes, and may not do so within an hour, in unopened and unexposed bloodvessels. Injections of oxygen into the circulation, or of peroxide of hydrogen into the trachea, may excite the heart or muscular system generally, but they do not restore the circulation through the lungs. The injection of vapor, and of hot water at the temperature of 120°, into the veins, excites the action of the heart in an extraordinary manner; whilst that of warm defibrinated and deoxygenated blood has no effect. Galvanism, applied to the heart jointly with artificial respiration, excites both sides of that organ, and, for a time, restores the pulmonary circulation. The forcible injection of blood into the jugular *vein*, with the view of overcoming the resistance to the motion of the blood in the lungs, entirely fails in its object. On the other hand, suction of the blood, by aid of a syringe introduced into a large *artery*, draws some of that fluid through the pulmonary capillaries, in an oxygenated state, and on its being reinjected into the artery, so as to reach, amongst other parts, the walls of the heart through the coronary arteries, effectually re-establishes the pulmonary circulation and all the functions of the body. The injection of the blood back into the artery, in a pulsatory or interrupted manner, revives the action of the heart most completely from its quiescent, cold, and partly rigid state, even *one hour and five minutes* after death. These interesting experiments, though not yet of practical application in the treatment of asphyxiated persons, serve to corroborate the generally-received opinion, that an essential fact in asphyxia, is the retardation, and subsequent arrest, of the movement of the blood through the pulmonary capillaries, and point to the relief or removal of that condition, as the turning-point of success in all attempts at resuscitation.

Effects of Breathing Impure Air.

Instances have occurred, in which the carbonic acid exhaled by large numbers of persons crowded together in small apartments has been most destructive to human life. The Black Hole of Calcutta was a room only 18 feet square, having two small windows; into this apartment, 146 prisoners were literally crammed, and, during one night, 123 of them perished. The cruelty of an enemy, in 1756, was scarcely more disastrous than the ignorance of the captain of an Irish passenger steamer, in 1848, who, during a storm, confined under closed hatches in a small crowded cabin, 150 passengers, of whom 70 died in the night.

But carbonic acid produces injurious effects, even when it exists, in the air, in quantities too small to cause asphyxia; as, for example, when not more than *one* per cent. is present. Thus, in ill-ventilated apartments, the presence of an excess of carbonic acid in the atmosphere, interferes with the proper oxygenation of the blood; for, as already mentioned, less and less carbonic acid is exhaled, as the proportion of that gas increases in the inspired air. Headache, oppression of the senses, lassitude of the muscles, and languor of the mind, are the results; the oxidation of the effete matters of the blood, is imperfectly performed or prevented, and they accordingly accumulate in that fluid; the pulmonary and cutaneous exhalations become still more loaded with such substances, and, together with the carbonic acid itself, and the ordinary exhalations from the skin and lungs—with which the air in such confined apartments is already infected—produce still more depressing effects upon, and ultimate injurious consequences to, the system.

During each minute, an ordinary adult inspires and expires 360 cubic inches of air, exhales 14.4 cubic inches of carbonic acid, and absorbs at least 15 cubic inches of oxygen; this renders 150 cubic inches of air totally irrespirable; for, as already mentioned, this condition is arrived at, when half the normal quantity of oxygen (30 parts in 150) is replaced by carbonic acid. But in order that the air of any room should be fit for continuous respiration, a much greater change must be effected in it, than that of merely replacing, minute by minute, the 360 cubic inches of air breathed in that time. For the 4 per cent. of carbonic acid contained in it, is sufficient, with the concurrent loss of oxygen, to deteriorate a much larger quantity of air. It is 100 times more than that which is present in common air, for this is only .04 per cent.; and therefore, even when diluted with 100 times its volume of ordinary air, the mixture would still contain twice the normal quantity of carbonic acid, viz., .08 per cent., or 8 parts in 10,000; this is about the average quantity in the air of certain large manufacturing towns. For such a dilution, 36,000 cubic inches, or more than 20 cubic feet of air would be required. Owing, however, to the rapid, spontaneous, dry diffusion of the carbonic acid, a less degree of actual dilution is sufficient for the purposes of healthy respiration; and it has been variously computed, that from 4 to 10 cubic feet of air per minute, which last-named quantity, with the respired air, would yield an atmosphere containing 12 parts of carbonic acid in 10,000, are needed for each person, in sleeping or sitting apartments, schools, courts, theatres, workshops, factories, barracks, workhouses, or prisons. Hospitals, especially for surgical cases or fevers, require at least double that quantity. Much depends on the temperature of the air, for a higher temperature requires a more rapid change. Moreover, besides the removal of carbonic acid and the renewal of oxygen, it is of the utmost moment that other pulmonary and cutaneous exhalations, which contain volatile organic matter and ammoniacal salts, should be diluted, oxidated, or removed. If the products of the combustion of artificial lights, especially of gas, enter the air of the room, a still further allowance of fresh air is necessary.

Were it not for the law of diffusion of gases, the evils arising from overcrowded and ill-ventilated rooms would be much greater. In the air of a very close room, which had been occupied by 500 people, and in which fifty candles had been burning, Dr. Dalton found, after it had been shut up for two hours, one per cent. of carbonic acid. But Dr. Roscoe has shown that in theatres, the percentage is usually .0321, and in schoolrooms .331; indeed, in no rooms did he ever find more than .5 per cent., owing, as he remarks, to the constant diffusion and interchange of air through the crevices and openings at the doors, windows, and fire-place. Furthermore, in proof of the rapidity and importance of the diffusion of carbonic acid in the air, he found that the percentage of carbonic acid was nearly uniform in every part of an occupied room, at the same time. Nevertheless, this accidental diffusion is insufficient for the proper change of the air in a crowded room. The escape and entrance of quantities of air are indispensable for the removal of the noxious products thrown off from the living body, and for the renovation of the atmosphere. This is to be accomplished, consistently with warmth and comfort, by *artificial ventilation.*

Besides this motion of the respired air, and its replacement by fresh air, a certain actual breathing space should be allowed for each person occupying private sleeping apartments, or for those attached to barracks, workhouses, prisons, and, especially, to hospitals. The day rooms being more or less constantly opened may be smaller. The practice of architects and builders, up to a recent date, was to allow not less than 800 cubic feet of space for each person; but this is too little, especially in infirmaries and hospitals, in which 1200 cubic feet per head are not considered too much, and for military hospitals in warm climates, as much as 2500 cubic feet per head have been recommended. The importance of sufficiency of breathing space and of ventilation, in sleeping apartments, *can hardly be overrated*, especially when we reflect that, even in health, the bedroom is occupied, from first to last, nearly 8 hours out of the 24, or nearly one-third of our existence. In hospitals and infirmaries, the same room is too frequently occupied both day and night.

The deterioration of health, from neglecting to sleep in a pure air, is shown in many ways. Many competent authorities attribute the deposition of tubercle in the lungs, *i. e.*, the early stage of phthisis, partly to inadequate respiration, and to imperfect oxidation of the constituents of the blood and tissues. Consumption appears to have been engendered in the Quadrumana confined in the small overcrowded monkey-houses of the London and Parisian Zoological Gardens; but after increased accommodation and proper ventilation were secured to those animals, tubercular disease almost disappeared from amongst them. The small, close, sometimes doubly-glazed houses in Wales, contrast with the open dwellings of the inhabitants of Skye, and so does the prevalence of consumption in the former, with its rarity in the latter, districts. At an infant school at Norwood, a great mortality occurred amongst the children, clearly dependent on imperfect ventilation. Similar experience might be derived from every large town in the kingdom, provided facts were always duly recorded and understood. In the infant hospital at Dublin, 2944 children died during four years, under a system in which ventilation had been utterly neglected; whilst in a similar period, during which many improvements in this respect were made, the mortality fell to 279. Sometimes the injury may consist in a lowering of the strength of the system, which exposes it to the attacks of impending epidemic or zymotic diseases. The effete matters retained in the blood, must deteriorate the fluids of the body, or, escaping into the air, they may form an organic nidus for the development of some diseases, or they may ferment, become putrescent, and so favor the multiplication and spread of poisonous fomites. Such effete matters may even undergo decomposition within the body. The lowered condition of health thus induced, favors the continuance of the evil practice of breathing impure air; for in this depressed state of the respiratory and other functions, the need for fresh air is less felt, and habit reconciles the senses, and dulls the perception, to the effects of the suicidal practice of inhaling an atmosphere poisoned by one's self. Persons accustomed to hot, close, unventilated rooms, loaded with a vitiated atmosphere, do not recognize, either by smell, or by the sensations of enfeebled bodily health and infirmity, the effects of the impurities which they breathe. Moreover, they often believe themselves, and are regarded by others, to be in an average state of health; but the onset of an epidemic, or of a contagious disease, reveals their want of power to resist morbid influences. As a most serious predisposing cause of disease and mortality, during such visitations, the overcrowding of rooms, whether large or small, public or private, is fully recognized.

The overcrowding of the population in parts of towns or villages, is always very inimical to health. This is doubtless partly to be explained by the fact, that it is the poorer classes, less well provided for, in every way, which occupy such neighborhoods; it is also partly due to the closer proximity of the inhabitants to each other, and to their increased liability, from this circumstance, to communicate diseases to one another. But the increased accumulation, within a limited space, as in towns, or in the immediate neighborhood of dwellings, as in villages, of the excreta, and of the waste animal and vegetable matters of the food, which constitute, when undergoing decomposition, sources of contamination to the air, cannot be here disregarded. Indeed, it has been shown that whereas, in the open country near Manchester, the quantity of organic matter in the air, is only 1 grain in 200,000 cubic inches, in the confined and overcrowded districts within that city, the proportion is, 25 grains in the same quantity of air.

The open ditches for drainage, and the heaps of garbage and refuse, in villages, and the uncleansed sewers, defective drains, and untrapped water-closets and sinks, in cities and towns, by admitting the escape of foul air into the environs, the lanes, the streets, or the houses themselves, are serious causes of insecurity to health. Sewer-atmosphere usually contains sulphuret of ammonium, or ammonia and sulphuretted hydrogen, frequently carburetted hydrogen, and besides these, it is loaded with *organic matter*, decomposing or putrescent, mixed with the spores of *fungi*, and with the minute living organisms known as *bacteria*, or, at any rate, with the organizable material in which these are generated. A house into which such an atmosphere is conducted, by an untrapped sink, or other defect, resembles, when closed at night, an inverted bell-jar over an open gas-pipe, or a receiver specially connected with the sewer, which acts as a retort for the evolution of poisonous vapors. It is necessary to exclude such chances of contamination of the air inside a dwelling-house; and to prevent also the contamination of the atmosphere in the immediate vicinity of the dwelling from which the internal supply for ventilation is derived. This is the immediate sanitary purpose of a perfect system of sewerage and drainage. Water is, for large cities certainly, and perhaps also, wherever available, the most cleanly and convenient vehicle for carrying away the excretory products of the inhabitants: the sewers should themselves be ventilated. Great care is needed to prevent the sewerage matter from contaminating wells, or other sources of drinking-water; for water is thus, as easily, and much more insidiously, contaminated than air. Earth closets are suitable for the country.

It seems probable, though but little is certainly known on these subjects, that zymotic diseases, whether contagious or epidemic, spread themselves, at least to a great extent, through the *air*, and enter the body through the lungs; moreover, it is possible that the agents which cause them, have, if not an organic *germinating*, at least a chemical *self-multiplying* property, and that impurities, whether in *solid bodies*, in *water*, or in *air*, may form a nidus for such increase or growth.

The mortality from epidemic and contagious diseases, both local and general, has been repeatedly demonstrated to be proportional to the impure condition of the atmosphere of houses or localities. On the other hand, a decrease in the amount and severity of zymotic diseases, and in the rate of mortality induced by them, has been shown to follow sanitary improvements in different towns. In the city of Salisbury, the annual average mortality during eight years previous to the complete drainage of the city, was 27 in 1000; whilst in the succeeding eight years, in was reduced to 21 in 1000. In the city of Ely, with a population of 6176 persons, living in 1200 houses, the average annual death rate, in the seven years from 1843 to 1849 inclusive, was 26 per 1000; in the year 1851, public sanitary works were brought into operation, and, in the seven years from 1851 to 1857, the death rate was reduced to 20½, whilst in the last of those years, it was only 19 in the 1000. Besides securing a larger supply of better water, 4000 cubic yards of cesspools were filled in, and trapped water-closets were substituted; but, in 1857, 200 houses were yet unconnected with the public drainage, and the pigsties were left, as being too sacred to be touched. It is noticeable, that, whilst the death rate in this city was reduced, subsequent to the sanitary improvements, from 26 to 19, the annual death rate in the surrounding country was still 21, in 1857. (William Marshall.) The annual mortality at Pau, one of the healthiest places in France, varies from 28 to 23 per 1000; the highest actual mortality in England is 45, the lowest is 11, and the average, 22, per 1000. A comparison with these figures indicates the sanitary position of the city of Ely. The death rate of 11 per 1000, is regarded as representing the *inevitable annual mortality* of this country; the additional deaths beyond that, constitute the *preventible mortality*, dependent almost entirely on zymotic diseases, the ravages of which might be more or less controlled by sanitary improvements. It has been quite recently shown, that one important and unexpected result of public sanitary improvements, is a marked diminution in the number of deaths from phthisis; this is probably due to the better system of drainage, and to a general elevation of the health of the inhabitants. (Dr. G. Buchanan.)

A supply of *pure water* to a town is of immense sanitary as well as economical importance. It facilitates the cleansing and purification of both dwelling-houses and streets, and thus assists in the improvement of the air. It substitutes a wholesome beverage, for that contained in unclean tanks or butts, or for the water of surface wells, which from the soakage of filth, from pigsties, stables, or cesspools, is frequently converted into a deleterious, or even directly poisonous, drink. Impure water may act, by slowly introducing into the system, organic matter undergoing more or less change, and probably, capable of deteriorating directly, or indirectly, the composition of the blood, and thus ultimately lowering the health, and rendering the body more subject to the influence of zymotic agents. At other times, the water may act as the *receptacle*, the *nidus*, and the *vehicle*, of such zymotic poisons. The evidence collected first by Dr. Snow, in the epidemics of cholera in Lambeth, and afterwards by the Rev. H. Whitehead, in St. James's, Westminster, and by others, at Epping, and elsewhere, concerning the influence of water in intensifying, or probably in communicating cholera, is too strong to be resisted, though it has met with but a tardy acceptance.

The use of water, free, if possible, from organic impurities derived from dwellings, or from other sources, is as essential to good health as pure air. Filtering and depositing beds fairly purify water, on a large scale; but in private houses, if any doubt exist as to the character of the drinking-water, special filtration through animal charcoal, or through the magnetic oxide, or the carbide of iron, or if this be too expensive, boiling, and subsequent agitation or exposure to a pure air, are desirable precautions.

In regard to public improvements, sanitary science consists in the perfection of cleanliness of the *town*, the *house*, the *water*, and the *atmosphere*. The cost of such improvements, and the great question of the utilization of sewage, have also an economical aspect. For the national welfare, it is essential that sanitary work should be done; but it is not necessary that it should be directly profitable, or even free from cost.

THE ORGANS AND FUNCTION OF RESPIRATION IN ANIMALS.

As already stated, respiration is usually either aerial, or aquatic, according to the medium in which an animal is fitted to live; but, in a few cases, both kinds of respiration are possible, as in the true Amphibia. Examples of aerial, and of aquatic breathers, are met with in the Vertebrate, Molluscous, and Articulate Subkingdoms; but in the Molluscoida and Annuloida, as well as in the Cœlenterata and Protozoa, the respiration is, in all cases, purely aquatic. The respiratory organs afford no grounds for classification.

Aerial Respiration.

The general principles, physical and chemical, on which this kind of respiration is performed in animals, are the same as those which govern the respiratory process in Man; but the organs concerned vary according to the animal, and exhibit wide departures from the form and structure of the apparatus in Man, as we descend in the scale.

Vertebrata.—In all *Mammalia*, the respiratory apparatus is similar in plan, and even in detail, to that of the human body. There is a complete thorax with movable walls, separated from the abdominal cavity by a perfect diaphragm, and containing lungs suspended freely in pleural chambers, resembling, in all essential particulars, those of Man. The respiratory movements are performed in the same manner; their frequency also has a general relation to that of the pulse. The respirations are fewer, like the beats of the heart, in the larger Mammalia than in the smaller ones, these latter requiring relatively, more frequent changes of air in the lungs, to maintain sufficient respiratory action for the development of heat, and for other purposes in their economy. In the Carnivora, the lungs are relatively much larger than in the Herbivora. The right lung is usually the larger. In the horse, and elephant, and in most Cetacea, they are simple in form; but more commonly they are divided into lobes; usually on the left side, these do not exceed three, and, on the right, five lobes.

In *Birds*, besides a typical symmetrical arrangement, as to position and size, important peculiarities in the respiratory apparatus are met with. The thorax and abdomen form but a single cavity, there being usually a rudimentary diaphragm only, which is spread out upon the base of the lungs, as in some Reptiles. In the ostrich tribe, however, the diaphragm approaches, by its greater development, the Mammalia character, and in the Apteryx, this musculo-tendinous partition is quite perfect. The *thoracic walls* are constructed on a modified plan. The sternum, here expanded into the large breastbone, which gives attachment to the muscles of flight, forms the greater part of these walls, and even supports the abdominal viscera; whilst the ribs, which have a peculiar angular joint between their sternal and vertebral portions, occupy proportionally a smaller part. The absence of the diaphragm, and the difficulty of expanding a thorax thus constructed, by any active inspiratory movement, have led, as it were, to a complete reversal of the mechanism by which the air is drawn into, and expelled from, the chest. In Mammalia, and in Man, inspiration is an active, whilst expiration is, to a large extent, a passive movement; but in Birds, expiration is active, whilst inspiration is chiefly, if not entirely, passive. In expiration, the large sternum is drawn towards the vertebral column by muscular effort; the ribs are approximated, and bent at the above-mentioned angles, and so the thoracic part of the thoracico-abdominal cavity, and therefore its contained lungs, are compressed, and air is driven from them. The expiratory muscles now cease to act, and the sternum, chiefly by the elastic resilience of the bent ribs, being drawn from the vertebral column, pressure is removed from the surface of the lungs, and air is inspired; the expansion of the lungs is probably favored by the contraction of the incomplete diaphragm, which is attached to their base. The condition of the thorax and lungs when at rest, corresponds with the state of distension, whilst active breathing begins by an effort to force air from the chest, and not to draw it in, as is the case in Mammalia. The *lungs* of Birds are somewhat flattened, and fixed to the back of the thorax; they are relatively smaller than in Mammalia; their lobules are very distinct, each having its own bronchial tube and bloodvessels. Their interior is extremely subdivided, or cellular; the sacculi or cells thus formed are at first supported by delicate cartilaginous trabeculæ; but some open into the ultimate air-cells. These cells are small; whilst the capillaries upon them are exceedingly numerous, and their network very close; and owing to the frequent communications between neighboring clusters of air-cells, and to other minute arrangements, come into relation with the air on both sides. These capillaries when injected seem to be varicose, and even to project into the air-cells, in such a manner as to appear naked, or not covered by mucous membrane; this view is adopted by some, though, more probably, an exceedingly delicate membrane exists upon them.

The high temperature, the active habits, and the rapid waste of tissue in Birds, are associated with a corresponding activity of the respiratory function. These animals absorb a larger amount of oxygen, and exhale more carbonic acid, in relation to their weight, than the Mammalia; they are also much more dependent on a due supply of pure air, than the latter, and are much more quickly asphyxiated. Two supplementary anatomical conditions, peculiar to Birds, must more or less aid in their active respiration. First, there are usually found in the neck, thorax, and abdomen, and even in the limbs, membranous bags, named *air-sacs*, into which the air gains access by extensions from certain bronchial tubes, which reach to the surface of the lungs, and there communicate with the thoracic or pleural air-sacs, from which other communications extend to the abdominal and remaining air-cavities. These air-sacs are highly elastic, have a few plain muscular fibres in their walls, and are lined by a fine, moderately vascular, and partially ciliated mucous membrane. Secondly, in many Birds most of the *bones* are hollow, and are filled with air. In certain Mammalia some of the bones of the face and cranium contain air; but, in most Birds, besides these bones, the vertebræ and sternum, and even the long bones, which in Mammalia and in the early condition of the Bird, contain marrow, such as the clavicle, humerus, and femur, and even the merrythought and shoulder bones, are, in the full-grown Bird, occupied with air, which finds access to their interior by special membranous canals leading from the adjacent air-sacs. When the trachea is tied respiration may be performed for a time through an aperture made in the arm-bone. These cavities in the bones are lined with a membrane which, as compared with that of the air-sacs, is highly vascular. In Birds killed suddenly, or destroyed slowly by drowning, the air in the air-sacs and bones is often charged with from 8 to even 15 per cent. of carbonic acid (Dr. Davy); respiratory interchanges of oxygen and carbonic acid probably, therefore, here take place between the air and the blood, and these cavities must be regarded, not so much as supplementary, as sub-respiratory chambers, for the increase of the surface of absorption and exhalation. But their importance, in this respect, has perhaps been exaggerated. An equal extension of respiratory surface, if that only were needed in the economy of the Bird, might have been obtained by a trifling enlargement of the lungs themselves. The membrane lining the cavities of the bones is not so vascular as a respiratory membrane usually is, whilst that of the capacious air-sacs is still less so; moreover, there are some Birds which have no air in the long bones, or even in other bones; such exceptions occur in various Orders, chiefly, however, amongst the smaller Birds, and some aquatic species; lastly, the Apteryx has no air in any of its bones, and is even destitute of air-sacs, excepting the pleural chambers,—in this respect being quite singular.

The high temperature of Birds has probably some other explanation than the presence of these sub-respiratory air-chambers. As already mentioned (p. 191), these air-sacs, and the air-cavities in the bones, cannot much diminish the weight of a Bird in the air, by the relative temperature of their contents, but they may aid in flight, by their distending and giving fixity to the thorax, which is the base of action for the wings; they may also, by the different pressure which is exercised upon them during flight, act as a sort of pneumatic apparatus for the movement of air through the lungs, at a time when ordinary expiration is necessarily interfered with.

In *Reptiles*, the highest of the Cold-blooded animals, the respiratory apparatus is well-developed; but in comparison with the Mammalia and Birds, the lungs, though even larger in proportion to the size of the body, are not nearly so minutely subdivided in their interior, as in the Warm-blooded Vertebrata. Besides this, neither the arrangements of the heart and large bloodvessels, nor the structure of the thorax, are so well adapted for the perfect distribution of the blood to the lungs, and for the continuous introduction of fresh air into the air-cells; lastly, the pulmonary capillaries are not so numerous.

The greatest diversity is met with in these animals as regards the structure and the mobility of the thoracic walls. In the Saurians, as in the Crocodiles and Lizards, the *thorax* is constructed somewhat after the Mammalian type, with movable ribs and a small imperfect sternum; in the Chelonia or Turtles and Tortoises, the walls of the thorax are completely immovable, being fused, as it were, into the carapace and plastron; whilst, in the Ophidians or Serpents, the thoracico-abdominal cavity is very capacious and expansible; the exceedingly numerous ribs are disconnected in front, owing to the complete absence of a sternum; they are extremely movable, and have powerful muscles attached to them. In the higher Saurians only, is any trace of a diaphragm found; no such structure exists in the Chelonia or Ophidia. The act of respiration is never performed in these animals by an inhaling movement. In this respect they resemble Birds; but they differ from these even more remarkably, for they all force air into the chest by an act somewhat similar to that of deglutition. Air being drawn into the pharynx by the depression of the hyoid apparatus and its attached soft parts, the posterior nares are then closed, and, by an elevation of the same parts, the air is forced down through the glottis into the trachea. Expiration depends chiefly on the elasticity of the lungs; indeed, almost entirely so in the Chelonian Reptiles, being assisted only by the abdominal muscles; whereas, in the Saurians and Ophidians, it is aided by the intercostal muscles and the resiliency of the walls of the chest. The *lungs* of Reptiles, Fig. 115, are large in proportion to their bodies, and in the Chelonia are attached to the sides of the chest. They are sometimes cellular and sometimes saccular. When they are cellular, as in the Saurians and the Chelonians, 3, the cells are few, and form large alveolar spaces, presenting, on a section, a spongy structure, the bronchial tubes being soon lost in the wide cellules, which communicate freely with one another. In certain Saurians the two lungs are unequally developed; and in the lower forms the lungs become much elongated, and smoother in their interior. In the Ophidians and snake-like Saurians it is the rule to find only a single, long, cylindrical, sac-like lung, in a fully developed state, viz., the right one; the left lung is either slightly or not at all developed. The single lung, when distended, reaches through the greater part of the cavity of the body, and is saccular; the portion nearest to the trachea, however, has its sides marked with numerous alveolar depressions or imperfect cellules, supported by a cartilaginous framework, and having vascular walls; the larger portion of the sac has smooth and slightly vascular membranous parietes, Fig. 115, 1. Even in the Crocodiles and Turtles, owing to the large size of the cellules, and to their slightly subdivided form, the pulmonary mucous surface, for the capillary network, is comparatively small; in the Serpents it is even proportionally less. Besides this condition, the less perfect nature of the inspiratory mechanism, the small quantities of air slowly and feebly impelled into the lungs, and the arrangements of the vascular system, imply a less active respiration, in accordance with their usually slower life and habits. In the aquatic Ophidia the buoyancy of the body is greatly aided by the size of the lungs, especially in the Turtles, the shell of which is of great weight.

In the *Amphibia*, which include the Frogs, Toads, Newts, Sirens, Proteus, and others, the anterior walls of the thorax are defective, and there is no diaphragm. The air, as in Reptiles, is drawn through the nostrils into the pharynx by the depression of the hyoid apparatus and floor of the throat, and is propelled through the glottis by the subsequent elevation of the same parts.

The lungs of the Frog, Fig. 115, 2, may be described as subcellular; the internal subdivision of their surface into cells is more simple than that of the Saurian reptiles, though more complex than the alveolar structure of the Ophidian lung. The corresponding bronchus opens at once into this subcellular lung, the alveoli at the upper part of which are supported by fine cartilaginous trabeculæ; it has been aptly compared to a single ultimate lobule of the lung of the Bird; but the layer of capillaries is single, and is exposed to the air on one side only. The respiration of the Amphibia is comparatively imperfect, and their blood is cold; moreover, it is partly performed by the surface of their moist skin, as has been proved by their continuing to exhale carbonic acid after the removal of both lungs, an operation which they for a time survive. Even in temperate climates, the Amphibia hibernate beneath the water; and in that state they respire solely by the skin; but in summer, simultaneously with a greater general energy, their respiration becomes more active, and then they breathe by the lungs also. The necessity for respiration increases in these and in other cold-blooded animals, with the elevation of the temperature of the surrounding medium, which excites them to greater activity of body. In the Siren and Amphiuma, the interior of the lungs is only slightly alveolar, presenting the last traces of a structure like air-cells; in the Proteus, the lungs are smooth on their internal surface like the air-sacs of the Fish; the trachea is membranous, and the glottis is a simple cleft.

Fig. 115.

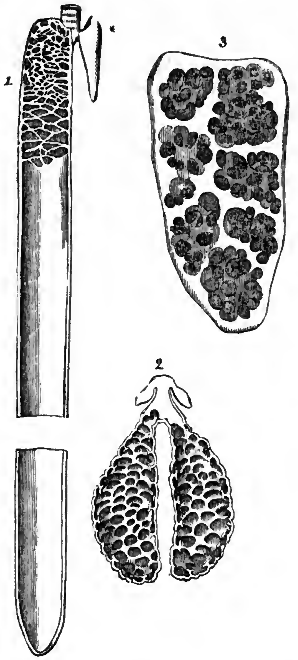


Fig. 115. 1, Lungs of a serpent; the right one only is fully developed; it is of such length, that the upper and lower portions alone are represented; the upper end is trabeculated and sacculated. 2, Lungs of the frog, showing their simple cellular character. 3, Portion of the lung of a turtle, showing its compound cellular structure.

In the early larval or tadpole state, all the Amphibia breathe aquatically, and some species retain the means of so doing in the adult condition; but all of them have lungs, however simple.

To *Fishes* the aquatic form of respiration is proper; but, as the homologue of the lungs of the other Vertebrata, the *air-bladder* of certain species requires mention. The air-bladder of the Fish is a simple membranous sac or bag, placed beneath the spine, sometimes elongate, cylindrical, or fusiform, sometimes pyriform, sometimes provided with simple diverticula, more rarely with short branched tubuli; sometimes it is double, one part being longer than the other, thus resembling the asymmetrical lung of the Serpents. The air-bladder always contains some air. It is usually a closed sac; but, in many cases, as in the pike, carp, salmon, and herring, it communicates by means of a short open duct, the *ductus pneumaticus*, with the œsophagus, near the stomach or higher up; in the Lepidosiren it communicates with the pharynx, and even opens into it by a slit like a glottis; it is also bifid and slightly alveolar, closely resembling, therefore, a simple saccular lung; it sometimes presents vascular projections in its interior. The idea that the air-bladder is the homologue of the lungs is supported by the fact, that in the embryos of the so-called pulmonated Vertebrata, the primitive lungs originate as little buds developed from the sides of the upper part of the œsophagus, which afterwards become hollowed out and branched. There is no homology between the gills and lungs in the Vertebrate series of animals; they have analogous functions, but they are totally distinct parts of the organism.

Certain fishes, as the Loach, can swallow air, which probably enters the air-bladder; but, in other cases, and especially when this organ forms a closed sac, air must be alternately excreted from the blood and absorbed by it, according as the bladder is full or empty. In the Amphioxus, the alimentary canal aids in the respiratory process. The analysis of the air in the air-bladder sometimes shows a large proportion of carbonic acid, and sometimes little more than nitrogen. In a few species, in which it is of great size, and communicates freely with the pharynx, the air-bladder may be regarded as a feeble sub-respiratory organ. In the great majority of cases, however, it is a rudimentary part, exercising little or no respiratory function; it is large in the Flying-fishes, and in some others capable of energetic and sustained exertion. As elsewhere mentioned (p. 187), when distended it diminishes the specific gravity of a Fish supported in water, and also alters the centre of gravity of the animal. It is usually absent in what are called ground-fishes, which live in deep water; but its presence or absence appears to follow no precise rule, either as regards the habits, size, or generic position of the Fishes in which it exists or is wanting.

Mollusca.—The Pulmogasteropods offer examples of Non-vertebrated aerial breathers; they are terrestrial in their habits. In the snails, for example, a large sac communicating with the external air by an aperture situated on the left side of the neck, is found in the shelled varieties beneath the back part of the mantle, in that portion of the body which occupies the smaller coils of the shell. It has numerous bloodvessels ramifying upon its walls, and is usually lined with cilia. This simple sac may be taken to represent the primitive idea of a lung, that is to say, a sac formed by an inversion of the surface of the body, lined by a thin moist membrane communnicating with the air, and possessing, distributed upon its walls, bloodvessels, which have thin coats and a constantly moving blood-current in them. Such an organ becomes perfected by increase of size, by multiplication of its parts, so as to constitute a multilobular lung, by subdivision of its internal surface into saccules or air-cells, and by the penetration of air-tubes into its numerous lobules. The remaining Gasteropods, and, indeed, all other Mollusca and Molluscoida, breathe aquatically.

Annulosa.—Numerous instances of air-breathing animals occur in this Subkingdom. Entire Classes, without exceptions, such as the Myriapoda, the Arachnida, and the extensive and most important Class of Insects, breathe in this way. Of the Annelida a few only are terrestrial and respire air; these, such as the earth-worms, have pairs of small sacculi opening on the sides of the body in each segment; but they are usually filled with mucus. Similar structures exist in the leech. The air-breathing Annulosa, generally, however, do not breathe by soft membranous compound sacs like lungs, or by soft air-bladders, or even by simple soft sacculi like those of the land-snails; but they have internal air-chambers, surrounded by stiff walls, so that they are kept constantly patent, and are not easily compressed.

In the *Myriapoda* these chambers are saccular, a pair of symmetrical sacs existing in each of the many segments of the body; they communicate by short membranous tubes, the walls of which exhibit spiral lines with little apertures on the sides of the segments, named *spiracles* or *stigmata.* From these sacs, in one species, forming a step towards the condition of Insects, other short twigs ramify into the body, or large symmetrical lateral trunks connect them all together. In this way air is conveyed into close proximity with the nutrient fluids, and respiratory interchanges are accomplished.

In the *Arachnida* air-sacs exist in the spiders, communicating immediately with spiracles or stigmata on the surface of the body, and frequently having their internal membrane *plicated,* so as to increase the surface for exposure to air, for the aeration of the fluids of the body. This plicated structure is associated with a more perfect condition of the circulation, and compensates for the comparatively limited distribution of the air in these active and powerful animals. In other Arachnida, the air-chambers are tubular, constituting trachea, as found in the mites.

The *Insects* possess in greatest perfection this particular modification of an aerial respiratory apparatus, viz., a series of almost incompressible canals or tubes, instead of sacs. In these exceedingly active and energetic animals, most of which are organized for flight, the respiratory apparatus consists, first of tubuli, which commence at the *spiracles* or *stigmata* found on each side of certain segments of the body, and, after a short course, lead into two longitudinal lateral tubes, extending from one end of the animal to the other. From these principal tubes, branches are given off for each segment; these branch again and again, until the finest ramifications penetrate the substance of every organ, especially the muscles, and even the ganglionic nervous centres, and the complex eyes. These tubuli, large and small, constitute the well-known *tracheæ* of Insects. They are recognized under the microscope, by the beautiful structure of their walls, which are composed of coherent spiral fibres arranged in the most regular manner, and maintaining by their elasticity, the whole tracheal system in a patent state, resisting the pressure to which they are subjected during muscular effort. By these open canals, air is freely introduced into every portion of the Insect. In many perfect Insects, especially in those of powerful flight, the body or abdomen is made to perform active movements, by which air is drawn in and out through the spiracles. Closure of the spiracles, or the filling of the tracheæ with oil, speedily asphyxiates these animals. Although, therefore, the circulatory apparatus is limited to a dorsal vessel, with large venous sinuses and interstitial lacunæ, without capillary vessels, yet the respiratory apparatus is diffused through every organ and portion of the body, and the aeration of the blood is most complete. The respiratory function of these, the most perfectly developed examples of the Annulose animals, is, in the majority of species, extremely active, in harmony with their general energy and comparatively high temperature. In the largest Insects, and in those which, though of smaller size, possess remarkable powers of sustained flight, as the Bee tribe, the longitudinal tracheal trunks are dilated in certain segments, so as to form *air-sacs* with rigid walls. The size of these presents considerable variation, being largest in species possessing the greatest powers of flight. The wings of the perfect Insect have no homology with the true limbs, for they spring from the dorsal, and not from the abdominal surface; in their structure and mode of evolution, they are more like respiratory organs, being filled with ramified tracheæ.

The tracheæ and their dilatations in the flying Insects, sometimes designated the Birds of the Non-vertebrate Creation, have been supposed, like the membranous and osseous air-cavities in Birds, to diminish the specific gravity of the body during flight, by the warmer air in them; but any such effect must be immeasurable. Their hollow, stiff structure, however, utilizes the material employed in the most admirable manner, and so relatively diminishes weight; whilst the large dilatations or sacs met with, especially in Insects of flight, may serve as store-chambers for air, the spiracles being, perhaps, more or less closed during that act.

Insects absorb, and convert into carbonic acid, a relatively large quantity of oxygen, even during rest; but the respiratory interchanges are much more active during locomotion. A bee will perform during the excitement immediately following its capture, as many as 125 respiratory movements of its body per minute; but after an hour and a half, these may decline to 46 per minute. In the first hour of an excited respiration, one-third of a cubic inch of carbonic acid has been found to be generated, a larger quantity than was produced in twenty-four hours by a bee in its quiescent state, and far more than is given off by the lungs of a Man, in proportion to his weight. (Newport.) In the larval condition, as exhibited in caterpillars and grubs, Insects are also provided with stigmata, lateral tubes, and tracheæ; and so is the pupa or chrysalis of those insects, which pass through the perfect stages of metamorphosis. But the respiratory process in the pupa is less active than in the perfect Insect, and in the chrysalis, less active than in the larva. It is curious that the larvæ of certain insects, as of the gnats and Ephemeræ or day-flies, and dragon-flies, are purely aquatic in their habits; but still, for the most part, they also breathe by tracheæ, the spiracles of which exist only in the hinder portion of the animal; these they protrude above the surface of the water, for respiratory purposes. In the larva of the gnat, one of the spiracles of the tail segment is provided with a tubular prolongation, the mouth of which, beset with fine setæ, which retain vesicles of air, is made to reach the surface of the water, so that the creature can breathe whilst the rest of the body is submerged, and the head turned downwards, in order to watch for its prey. The larvæ of the Ephemeræ, still more curiously, breathe by external tuft-like or leaf-like thoracic or abdominal gills, connected with the tracheæ, or by similar organs situated in the intestinal canal; but in the perfect state, like other Insects, they breathe by tracheæ. Aquatic beetles come to the surface to breathe, or carry globules of air below the water. The same habit prevails among certain Arachnida, some of the water-spiders even building nests beneath the water, and carrying down air to them, which they can afterwards respire.

Aquatic Respiration.

In this form of breathing, the physical process concerned is simply that of the *moist* or *false diffusion of gases* in a state of solution, those of the blood or nutritive fluids of the animal interchanging with those of the water, which, whether fresh, brackish, or marine, is the universal medium of aquatic respiration. That water contains air, is shown by placing it under the air-pump, or by boiling it, which processes abstract or expel the air, and render it unfit to support aquatic animal life. The quantity of free oxygen contained in water is, of course, much less, volume for volume, than it is in air, inasmuch as the source of the oxygen is the air itself, held in solution. But the air, dissolved in water, is somewhat richer in oxygen than the ordinary atmosphere; this is explained by the fact that oxygen is twice as soluble as nitrogen, in that fluid. Nevertheless, the gaseous interchanges in aquatic respiration, are necessarily slower and less energetic than in aerial breathing. The temperature of aquatic breathers is low; they maintain a heat very little raised above that of the surrounding medium, which is also a much better conductor of heat than air, and so robs them quickly of their caloric; their movements and other vital acts are comparatively sluggish and slight; their life is more vegetative, and even those which have a perfect circulation, are characterized by possessing cold blood. The Mammalian aquatic species, such as seals, porpoises, and whales, though chiefly or entirely inhabiting the water, are yet air-breathing animals provided with lungs, and warm-blooded.

In water-breathing animals in which a distinct circulation of blood exists, a special respiratory organ is always present, connected with the circulatory apparatus. With the exception of Insects, this is true likewise of air-breathing animals. The more perfect the circulation, the more carefully must respiration be provided for; otherwise, carbonic acid, accumulating in the blood, would be speedily conveyed to the nervous centres, and produce rapid poisoning. Such an event is more imminent in the warm-blooded air-breathing, than in the cold-blooded water-breathing animals.

The most perfect breathing apparatus for *aquatic* respiration, consists of exceedingly vascular projecting membranous processes of various forms and complexity. In the lower animals, such processes are more simple, and in the absence of a distinct circulation, they are ciliated upon their surface. These projections are named *branchiæ* or *gills;* they differ in structure, as much as the lungs of the air-breathing animals. Again, in certain forms of aquatic animals, and in some Entozoa, there are found, with or without gill-like projecting organs, remarkable internal ramified tubes or vessels, communicating, by an opening, with the surface of the body, and partially ciliated in their interior; these are the so-called *water-vessels* or water-vascular system; they appear to have a respiratory office. In still lower aquatic animals, destitute altogether of vessels, certain hollow ciliated portions of the surface, or interior, of the body, exist, named *ciliated sacs;* in others, *ciliated discs* are present; often the cilia are methodically arranged on the surface, or in the interior of the body; lastly, in the lowest forms, these microscopic moving organs cover a portion or every part of the minute organism, and so are auxiliary to respiration.

Vertebrata.—The highest of this Class which have gills, are the *Amphibia.* In the larval or tadpole condition, all these animals have minute gills, and frequently even two sets of these organs. The first set are called the *external gills*, and consist of soft processes slightly branched, or very much subdivided, or even plumose; they are attached to the side of the neck and project freely into the water. In the larva of the higher or tailless Amphibia, the frogs and toads, the external gills remain only for a few days; but in the tailed salamanders or newts, they exist for a longer period, and in the lowest Amphibia they persist throughout life. They are, at least when newly developed, always covered with cilia, and each minute subdivision or branch contains a looped capillary vessel, one side of which conveys outwards the deoxygenated venous blood, and the other inwards the oxygenated or arterial blood. The second set of gills, found in certain Amphibia only, are named the *internal gills;* these appear in frogs and toads after the wasting of the external gills; they consist of minute fringes of vascular processes attached to the cartilaginous branchial arches of the hyoid apparatus, and are protected by a fold of the skin of the neck, so as to lie in a sort of *branchial chamber*, which communicates with the pharynx; the opening on the right side of the neck very early becomes closed. Water reaches these internal gills, by flowing in through the mouth or nose, and then out through a small orifice on the left side of the neck, the movement of the water being caused by an act resembling that of deglutition. It is these internal gills, found in some of the Amphibia, which are the representatives or homologues of the gills of Fishes; they are not developed in Menobranchus and Amphiuma. In the frogs, toads, and true salamanders, both sets of gills disappear; hence these are named *Caducibranchiate* Amphibia; they afterwards breathe by the lungs and skin only. In the salamandroid *Perennibranchiate* Amphibia, including the Axolotl, Menobranchus, Siren, and Proteus, the gills are persistent; they are really the external gills, though they may become attached, as in the Axolotl, to the first branchial arch of the hyoid apparatus.

In *Fishes*, the branchiæ or gills, which are always internal or covered, attain their highest development and most complex forms. They usually consist of numerous comb-like processes, supported, like single or double fringes, on the branchial arches of the hyoid apparatus, and forming four or five laminæ on each side of the pharynx. They are, in some cases, as in the Cartilaginous Fishes, concealed by the integuments; but in others, as in the Osseous Fishes, by a movable osseous and cutaneous covering, named the *operculum*. In the latter case, only *one external gill opening* exists on each side, the operculum overlapping all the branchial arches; but internally the gill-chamber opens into the pharynx, by separate clefts or apertures between the branchial arches. In the former case, however, the gill-chamber is completely divided into passages, varying from *three* to *seven* in number, each having a separate internal and external aperture, corresponding with the clefts or spaces between the branchial arches. In some of the lowest forms, the gills are mere folds of membrane, lining distinct sacs. In the Myxine, the branchial outlets unite into a single canal, which runs backwards, and opens on the under surface of the fish, at a sort of abdominal pore.

The extent of surface obtained by the comb-like fringes of the gills of Fishes for exposure to water, is very large, especially in the rays and skates. The water drawn into the opened mouth is forced, at intervals, by the hyoid and pharyngeal muscles, between and over the gills, in the direction of their fringes, and is rapidly expelled at the sides of the neck, the action, as seen in an ordinary fish, being accompanied by regular movements of deglutition, and by a characteristic opening and shutting of the opercula. In the Cartilaginous Fishes, the water passes in streams from the lateral openings, which are sometimes more or less valved. Drawing a fish rapidly backwards in the water, may asphyxiate it, by bending up the branchial fringes, if the opercula be open, or by exclusion of water, if these be closed. Each fringe-like process of a gill-plate, is supplied by a branch of the *branchial artery*, which brings dark or venous blood from the heart and bulbus arteriosus; this divides into minute vessels, which end in the *branchial capillaries;* from these again, the *branchial veins* arise, which pass back to the base of the gill, and all combine to form the aorta. In passing through the gills, the blood is oxygenated. As the heart of the Fish is branchial, all the blood returned from the body is propelled through the gills, before it is again distributed to the body; nevertheless, the respiration of fishes, being aquatic, is feeble, and their temperature is cold. The gills of fishes are not ciliated on their surface; but it is necessary that they should continue moist, or the usual respiratory interchanges between the blood and the air dissolved in the water, would soon cease. Respiration will, however, go on for a short time in the air, provided that the gills remain moist. Certain fishes, as the eel and others, leave the water for a time. The Anabas, of Ceylon, is said even to climb up trees and bushes after food; on the sides of its head, just above the gills, the pharyngeal bones are convoluted, and the anterior branchial arches support chambers with laminated walls, for holding quantities of water. Fishes are necessarily suffocated when removed from the water, the gills becoming first clogged and then dry, circulation and respiration in them being both arrested. They are also asphyxiated in water which no longer contains oxygen in solution, or even when foreign substances are dissolved in it; sugar speedily destroys them. In that exceptionally organized marine animal, the Amphioxus, the mouth is provided with ciliated *lobes*, which, by ciliary action, propel the water into the pharynx.

This cavity is dilated, has its sides supported by a complex lattice-work of branchial cartilages, upon which the branchial vessels are placed; its sides are perforated by numerous slits, upwards of 100 in number, the edges of which are ciliated, and which lead into the perivisceral cavity of the abdomen. The water used for respiratory purposes is expelled from this cavity by an opening named the *abdominal pore*. Moreover, the entire alimentary canal is ciliated internally, and the water which passes through it may also be employed in the aeration of the blood.

On comparing the entire series of the Vertebrata, as regards their mode of respiration, it is seen that, in the adult state, the Mammalia, Birds, Reptiles, and Caducibranchiate Amphibia, breathe by lungs; that the Perennibranchiate Amphibia, and the tadpoles of the Caducibranchiate kinds, breathe both by lungs and gills; and, lastly, if we disregard the sub-respiratory air-bladder occasionally present, that Fishes breathe entirely by gills. The respiratory process in these animals is, however, much more active than in the aquatic Non-vertebrata, which we have next to describe. This is due to the comparatively greater size of the gills, to their more perfect and complex structure, to the special contrivances for moving the water over their surfaces, and to the proximity of the heart to these organs.

Mollusca.—Of these chiefly aquatic animals, the most highly developed gills exist in the highest Class, the Cephalopods, in which the branchiæ, being very large, but nonciliated, consist of foliated laminæ, united by a common stem, which supports the branches of the branchial arteries and veins. The gills are lodged, one or two on each side, in the cavity of the nonciliated mantle, which has two orifices, one by the side of the neck, at which the water enters, and another placed at the extremity of the tubular process, called the funnel, from which the water passes out. The movement of the water is accomplished by the alternate dilatation and contraction of the muscular walls of the mantle. In the Pteropods, the branchiæ are also laminated, being placed sometimes within, and sometimes without, the mantle, and being always ciliated. In the naked species of Branchio-gasteropods, the gills consist of ciliated, fringed, sometimes tubular processes, projecting into the water (Nudibranchiata), and arranged either along the sides of the body in tufts (Tritonia), or else in a circular disc-like manner on the dorsal region (Dorsibranchiata), or around the lower opening of the alimentary canal (Doris); sometimes a fold of the mantle partially or completely covers them. In those kinds which have univalved shells, the gills consist of ciliated plicated fringes, lodged in the last spire of the shell, the water gaining access to the cavity in which they are contained, sometimes by a long tube, and sometimes by a wide opening. Amongst the lowest branchio-gasteropods are some species allied to the Nudibranchiate group, which have no branchiæ, but are believed to respire by means of their surface only, or by that, aided by certain ciliated extensions of the digestive cavity. A few genera, such as Onchidium, possess, besides arborescent branchiæ, distinct air-sacs, showing a transition between the branchiate and pulmonate divisions of the Gasteropoda. In the bivalved Lamellibranchiata, mussels, oysters, and others, the gills consist, as their name implies, of two pairs of flat laminæ, composed of a double layer of membranous rods, covered with fine cilia, and supporting the bloodvessels. In some genera, those branchiæ are freely exposed when the valves of the shell are open (oyster); in others, they are inclosed by the ciliated lobes of the mantle, at each end of which an aperture exists, for the entrance and exit of the water, which is driven through by ciliary action.

Molluscoida.—Amongst these, which are all aquatic, the Ascidioida possess, in the anterior part of the body, large *respiratory atria* or *chambers*, or branchial sacs, lined with cilia, and communicating with the exterior. These atria are formed by an expansion of the part formerly named the pharynx, which is supported by a rod, called the *endostyle*, the sides of which are, in some species, cleft by numerous slits, through which water passes into an interval between the branchial atrium and the proper walls of the body, and then escapes at the opening of the mantle. In the Brachiopoda, the cavity of the mantle itself is the chief respiratory chamber; it presents vesicular dilatations covered with vessels, which probably act as gills. In the Polyzoa, the perivisceral cavity, which contains nutrient fluid, is prolonged into the numerous, delicate, tentacular processes, arranged around the oral aperture, which are covered with rows of beautiful cilia; hence the fluid in their interior is aerated by the currents of water on their surface.

Annulosa.—The aquatic Annulosa are represented only by the Crustaceans, and the Tardigrade Arachnida. In the larger Crustacea, the gills or branchiæ present the form of flattened laminæ, which, in the higher forms, such as the lobsters and crabs, are inclosed in proper branchial cavities within the shell; in the lobster, there are twenty-two branchiæ on each side. Through these cavities, copious streams of water are propelled by the continual movements of special flapping organs, consisting of the last joints of some, or all, of the abdominal limbs, which are flattened out for that purpose.

In the land crabs, which are drowned if kept in water, but which remain on land a long time, the gills are moistened by the watery contents or secretion of a spongy or laminated organ, situated, with the gills, in the gill-chamber. In still lower and smaller Crustacea, the branchiæ consist of delicate foliaceous or flabellar organs, attached to the under side of the segments of the body, which project into the water, and are usually kept in a constant state of motion. In the Crustacean Onisci, or wood lice, and allied forms, which inhabit moist places, there exist, near the covered gills, networks of air-tubes, or even air-sacs, thus approaching the Insects. In some of the lowest aquatic Arachnida, as the Pycnogonida, no special respiratory organs have been detected. No cilia exist in any of the aquatic Arthropodous Annulosa. It has already been mentioned that the larvæ of certain Insects which live in water, breathe by gill-like appendages connected with the abdomen, or with the intestinal canal. The *Annelida* or worms are generally branchiated; the gills are composed of a highly-divided delicate membrane, either branched or tufted, and usually ciliated; they are sometimes external, and situated either on the back, on every segment of the body, as in Nereis and Eunice, or around the head only, as in Serpula; sometimes they are internal or covered, as in Polynoe; or they are represented merely by ciliated sacs, as in the leech.

Annuloida.—These are, also, either aquatic, or parasitic in the interior of other animals. Such as have soft integuments probably respire through the skin. None ever possess branchiæ; but special provisions for the respiratory function are met with. Thus, in all the worm-shaped Scolecida, there exist peculiar ramified contractile vessels, the trunks of which open on the surface of the body, and are in part ciliated in their interior; these are the so-called *water-vessels*, which are supposed to be subservient to the respiratory process. In the Rotiferous animalcules, ciliated discs of the most varied shape perform this function. In the Echinodermata, respiration seems also to be performed, partly by the sides of the perivisceral cavity which communicates generally with the exterior, admits the sea-water, and is lined with cilia; and partly by the contractile ambulacral vessels, which can also be distended with fluid. In the Holothurida, the perivisceral cavity is closed; the ambulacral system is reduced to its lowest condition, but important ramified tubular organs, communicating by a trunk with the cloaca, and projecting into the perivisceral cavity, are regarded as respiratory organs; they are contractile and are lined with cilia.

Cœlenterata.—All of these are aquatic. They possess no distinct circulatory organs, and accordingly no separate respiratory apparatus; respiration seems to be accomplished by the interchange of oxygen and carbonic acid, indifferently through any part of the external surface, or specially perhaps at certain ciliated portions of the internal surface of their body-cavities, and within the numerous ciliated tubular prolongations of that cavity, which ramify in the soft disc of some of those animals.

Protozoa.—These universally aquatic animals exhibit the same want of distinct respiratory organs, unless the *contractile vesicles* be of this character. In the Infusoria, more or less of the surface of the body is ciliated. In the Sponges, the tubular passages through the body form respiratory surfaces, being, in many species, provided at certain points with cilia. Lastly, in the Rhizopods, or Foraminifera, and in the still humbler Gregarinida, not even cilia are present; but the almost structureless or simple cell-like body of these animals must be stimulated, disintegrated, and purified, by direct absorption of oxygen, and exhalation of carbonic acid, so far as is necessary for their simple life.

The presence of *vibratile cilia* on the respiratory surfaces of the lower forms of most aquatic animals, is a noticeable anatomical fact; they often occur in the embryonic, if not in the adult condition. They serve, when present, to change continually the stratum of water in immediate contact with the breathing surfaces; and, according to some, their motion is even to be attributed to the active chemical changes which take place on those surfaces. They are not, however, essential, for they are not always present. Their absence from the branchiæ of the Cephalopods, amongst Mollusca, and of the Crustacea, amongst Annulosa, form the most striking exceptions. Amongst the aquatic Vertebrata, they are not found on the gills of fishes, unless upon the branchial apparatus of the singular Amphioxus; they exist on the temporary gills of the Amphibia, but probably not on the permanent gills of the Perennibranchiate forms. Amongst air-breathing animals, they are wholly absent in the sacs or tracheæ of the higher Annulosa. In the lowest air-breathing Vertebrata, viz., the Amphibia, they exist in the lungs as well as in the respiratory passages; but, in all other instances, they appear to be confined to the air-passages and air-tubes, not extending to the air-cells. It must also be remembered that they are found on other organs besides those concerned in respiration.

ANIMAL HEAT, LIGHT, AND ELECTRICITY.

ANIMAL HEAT.

Inorganic bodies have a constant tendency, by losing or gaining heat, to adapt themselves to the temperature of surrounding media or objects. They may also be artificially cooled, or artificially heated, to all possible degrees. The same is true of dead organized bodies, within the limits of combustion, as of a dead tree, or of a dead human body. Living plants and animals also receive, or give off, heat physically, but they have, besides, a common power of resisting external temperatures; with plants, this power is very feeble, but with animals it is more marked. In the higher animals especially, there is an inherent power of maintaining a temperature differing from that of the surrounding media, which are in general cooler, but may be warmer, than their own bodies. Moreover, each kind of animal is able to maintain, within a certain range, a temperature proper to itself; but, since even living animals, like dead ones and inorganic bodies, exhibit the same physical phenomena of absorption, conduction, and radiation of heat, they undergo constant changes, usually in the direction of a loss of heat. Hence, there must exist within them a power of constant renewal, or production, of fresh heat. The standard temperature of an animal is understood to express its proper heat; whilst the form of heat produced in its body, for the maintenance of this temperature, is known as *Animal Heat*.

This function of producing heat is universal in the Animal Kingdom, and all the processes of animal life are influenced by it.

Animals have been divided, according to their temperature, into the *Cold-blooded* and the *Warm-blooded* animals, the former being understood to include all the Non-vertebrate animals, and, amongst the Vertebrata, the Fishes, Amphibia, and Reptiles; whilst the Warm-blooded animals consist of the Birds and Mammalia, including Man. Amongst the Non-vertebrate Classes, the Protozoa and Cœlenterata, having no proper blood system, can hardly be designated cold-blooded ; yet they have a close relationship, as regards the phenomena of temperature, with that division of animals. It has been proposed to name the Cold-blooded animals, *animals of variable temperature*, and the Warm-blooded creatures, *animals of constant temperature;* because the former have their actual temperature greatly influenced by, that is to say, elevated or lowered, according to corresponding changes in the temperature of the media in which they live; whilst, on the other hand, the latter exhibit nearly a uniform temperature, under important alterations in that of the surrounding media. (Bergmann.)

In regard to the Protozoa, it has been shown, that when water containing Infusoria, is frozen, these minute creatures are not always necessarily destroyed by being likewise frozen, but each survives for a certain time, surrounded by a little uncongealed watery space; this can only be accounted for, on the supposition that the animalcule continues to produce a minute quantity of proper or individual heat. In the aquatic Non-vertebrate animals generally, a similar power of resisting cold exists ; though there are but few observations on the heat-producing powers of these animals. The temperature of a number of earth-worms, leeches, slugs, or snails, collected in heaps, has been found to be from $1\frac{1}{2}°$ to $2°$ higher than the air. In the air-breathing Insects, the heat evolved in the larval or caterpillar stage, is sufficient to maintain the body from $\frac{1}{2}°$ to $2°$ in the Lepidoptera, and from $2°$ to $4°$ in the Hymenoptera, above that of the surrounding medium. In the chrysalis stage, the temperature is nearly that of the surrounding medium, very little heat being evolved. In the perfect Insect, the temperature may vary in the bee from $3°$ to $10°$, and in the butterflies from $5°$ to $9°$, above that of the air. The temperature of bees, in numbers, as in a hive, may be as high as $16°$ above that of the air. The nursing bees sometimes reach a temperature of $22\frac{1}{2}°$ above that of the atmosphere. Insects, therefore, under certain circumstances possess a heat-producing power nearly equal to that of the warm-blooded animals. The temperature of bees is raised by exercise and excitement, and diminished by rest, sleep, hibernation, and want of food.

In Fishes, the temperature of the blood is usually from $\frac{1}{2}°$ to $1°$ warmer than the surrounding water at mean temperatures. In other instances, it is $2°$ to $3°$ higher, and in a few exceptional cases, in which the muscles and the blood are darker, the heart is larger, and the gills provided with enormous nerves, as in the tunny and bonito, the temperature is still higher; that of the bonito has been found to be $99°$, or $18\frac{1}{2}°$ above the temperature of the sea. (Davy.) In the frog, when the external medium has a temperature of about $60°$, the animal is from $\frac{3}{5}°$ to $1\frac{1}{3}°$ warmer than it; but when the external temperature is lowered to about 43°, then the animal is from 2° to 3½° warmer. The edible frog, inclosed in ice at 21°, has exhibited a temperature of 37½°.

In Reptiles, the temperature of the body is still higher, though yet it is dependent on the external temperature. The turtles produce less heat than the serpents, crocodiles, and lizards; the temperature of some of the latter has been found to be 86°, that is, 15° higher than that of the surrounding air. These facts show that in the cold-blooded animals, the temperature is greatly dependent on, and regulated by, that of the surrounding medium, but also that there is a moderate individual heat-producing power even in them. This power, moreover, absolutely increases, like the functions of the animal generally, at still higher temperatures; but yet so as not to enable the animal to reach that temperature.

In the *Warm-blooded* animals, the temperature is high and constant, and, as already mentioned, is, within certain limits, plainly independent of the external temperature, owing to special powers exercised within their bodies. Amongst the Mammalia, the average temperature of the body is lower than that of Birds, which present the highest temperature of any animals, although their general organization places them in a lower rank than the Mammals. The ordinary range in the Mammalia, is from 97° to 104°; in Birds, it varies from 100° to 108°, or even 111°. In the sheep, the temperature has been found to be from 103° to 105°; in the pig, 106°; but in the Arctic fox, it has been found to be 107°, the air being only 14°. In sea-birds, as in the gulls, the temperature is lower than in other birds, varying from 100° to 105°; in the common fowl it ranges from 107° to 110°, according to the climate and season; and in the swallow, it is even 111¼°. (J. Davy.)

The temperature of the tissues of the *human body*, speaking generally, ranges between 98° and 100°; but that of the blood, which is the hottest part of the organism, ranges from 100° to 102°. The blood varies in temperature in different parts, being the hottest in the hepatic veins, which bring the blood from the liver; this blood is somewhat warmer than that of the *vena portæ*, and even 1° higher than the blood of the aorta. (Bernard.) Directly opposite statements have been made as to the temperature of the blood, before and after it has passed through the lungs; but the most recent researches favor the conclusion that the blood in the left side of the heart is nearly $\frac{1}{5}$° lower than in the right side of that organ; a slight cooling process is supposed to occur in the lungs from the air admitted into them. The blood of the superficial veins of the limbs, coming from the exposed skin, is naturally cooler, from the influence of the atmosphere, than that of the arteries, which lie deeper; the temperature of the blood in the deep veins, as in the femoral vein, is also said to be about 1° cooler than that in the femoral artery. (Becquerel and Breschet.) The relative warmth of the organs and tissues, always less than that of the blood, depends on their vascularity, their distance from the central part of the body, or their proximity to the surface, and on the degree to which they are protected by external covering. Thus, whilst the temperature in the abdomen (in the bladder), has been found to be nearly 102°, even higher than that of the thorax, the temperature under the tongue is about 98°; and in the axilla 96°; that of the hands and feet may ordinarily be from 9° to 12° cooler than the central parts, *i. e.*, from 90 to 93°.

Various conditions modify the temperature of the human body; neither *age* nor *sex* produce any remarkable difference. The temperature of infants and of old persons is about normal, so long as they are placed under favorable conditions of protection. But the power of infants and very young children, as well as of the aged, to resist the lowering effects of cold is less than in the adult. Experiments on the young of Mammalia and Birds, show this; their small bodies, and also those of the human infant, will cool comparatively more rapidly, by radiation and conduction, than those of adult animals and Man; their calorific power may be as great, but they cool more quickly. Hence the greater necessity for the protection of clothing, and for artificial warmth.

The influence of *race* is also slight or ineffective. In hot *climates*, and in hot *seasons*, the mean temperature of the body is somewhat higher than in cold climates and seasons, the difference being more marked in animals than in Man. The difference, however, usually amounts to not more than from 1° to 2°, showing how slight is the influence of climate, and proving the independence of the temperature of warm-blooded creatures of external changes. According to Dr. I. Davy, however, in a long series of observations, whilst the external temperature varied as much as 22° Fahr., *i. e.*, from 60° to 82°, that of the body fluctuated 5.5° Fahr., *i. e.*, from 96.5 to 102°. The power of Man to resist, and accommodate himself to, climatic variations of temperature, is greatly aided by shelter, clothes, fire, means of cooling the air, and peculiar selection of food; he can create an artificial climate, and protect himself against its hostile influences. *Sleep* lowers the temperature of the body from 1° to 2°, all the organic functions, even circulation and respiration, being at that time likewise less active. No constant *diurnal variations* of the temperature of the body, in Man, have been observed; but, in Birds, the highest temperature seems to be attained at noon, and the lowest about midnight. (Chossat.) *Exercise* increases not only the sensation of warmth in the body, but actually raises the average temperature; the effects, however, being by far most evident in the extremities. Thus, the general temperature after quick running, may become nearly 2° warmer; after walking, the deep-seated parts show little or no change, whilst the feet and hands are raised many degrees, the action of the heart and lungs being quickened, as well as that of the muscular system generally, so that more rapid metamorphoses take place (pp. 813, 844). Deficient *food* and positive abstinence, lower the temperature; why, will be explained hereafter; on the other hand, abundance of food and the use of stimulants, ultimately increase it; but the immediate effect of a meal, or of taking wine, is said to be temporarily to lower the animal heat. The depression of the temperature, observed in animals in which the skin is covered with an impermeable varnish, has already been mentioned (p. 795). According to Becquerel and Breschet, in rabbits so treated, the temperature falls speedily from 100° to about 75°, before death takes place. The change in the color of the fur or feathers to white as winter approaches, in the case of Arctic mammalia and birds, retards radiation, and so conserves their animal heat. In *disease*, the temperature of the human body has been found to rise or fall many degrees above, or below, the normal temperature. Thus, in fevers with acceleration of the pulse and respiration, in active phthisis, in pyæmia, and other diseases, temperatures of 104°, 106°, and 108½°, have been noted, and in tetanus of 110¾°, *i. e.*, nearly 10° higher than the normal standard. On the other hand, in asthma and in cyanosis, or the so-called blue disease, in which, owing to a communication between the right and left auricles of the heart, the blood is imperfectly oxygenated in the lungs, the temperature of the body is unnaturally low; this is also the case in syncope, apparent death, and cholera, in which last disease, the blood becomes so thickened as scarcely to circulate. In the stage of collapse in cholera, the temperature of the surface of the body may be, according to different authorities, as low as from 80° to 67°, *i. e.*, from 15° to 28° below the ordinary temperature of the exposed skin. The sensation of heat, or the opposite one of cold, experienced by a person in disease, does not always correspond with the actual temperature of the body; for in the cold stage of ague, though the feeling of cold is extreme, the temperature of the body may be actually raised (p. 374). On the approach of *death*, generally, with a feebler pulse and respiratory action, combined frequently with the evaporation of profuse perspiration, the temperature is gradually lowered: first, in the hands and feet, then in the forehead, ears, and nose, and afterwards in the parts nearer to the centre of the body. It has been observed, not only in cholera, in which the temperature of the body is lowered from the disease during life, but also in yellow fever, in which the body is hotter than natural, that the temperature after death undergoes an actual elevation; this is probably to be accounted for, by the conduction of heat from the central parts, together with the cessation of the cooling influence of the evaporation of the cutaneous exhalation.

After death the cooling process goes on in accordance with the physical laws which regulate the temperature of inorganic moist bodies, the rate at which this cooling takes place depending chiefly on the external temperature and relative motion of the air, on the degree of exposure of the body, its condition of emaciation or obesity,—fat being a bad conductor,—and on the conducting power of the clothes, or other objects in immediate contact with the corpse.

Effects of Cold on the Human Body.

The power possessed by the human body of maintaining its proper temperature, independently of external conditions, is limited within certain ranges; conditions of cold or heat are met with which not only produce great inconvenience, but which, in the absence of special protection, may exercise a fatal influence. It has been shown experimentally, that, when a Mammalian animal has lost about 20° to 21°, or about ¼th of its normal heat, it suffers so greatly that a further loss of heat is fatal to it, death ensuing from debility or congelation. On the other hand, an addition to the temperature of the body of a Mammiferous animal of about 13°, is equally serious, constituting a limit beyond which death speedily occurs. Hence, in Mammalia generally, an artificial elevation of the temperature of the body is sooner fatal than an artificial lowering of that temperature. The same is probably true of Man, a greater range of temperature, in disease, having been observed previous to death, in the descending than in the ascending scale of warmth. The relative degrees of external heat and cold, which are endurable by Man, with proper precautions, in the different climates of the world, also prove that he can sustain, without injury, a greater diminution than an elevation of the external temperature. In the Arctic regions the thermometer has been recorded at temperatures as low as from —55° to —70°, the latter temperature being no less than 170° below the normal temperature of the blood; whilst, in the other direction, the highest temperature registered in the tropics is about 130° in the shade, viz., about 30° above the blood heat. Man is much more readily inured to cold than to heat; and the inhabitants of temperate regions, when they remove to the tropics, require to be more specially acclimatized, and can scarcely avoid becoming ill; whilst, in removing to colder latitudes, with due precautions, health may be more easily preserved. Nevertheless, cold, to the feeble and aged, is the great enemy of animal life, and the chief remote cause of human mortality.

When the living human body is exposed to the prolonged action of extreme cold, without protection, a gradual benumbing of the sensibility, a lowering of the circulation and respiration, and a general torpidity of the system, are produced. These effects occur more readily in children, and in infirm, ill-fed, or starved persons, and also in aged persons; and lastly, in those who are previously overcome by fatigue, or by the narcotic effects of alcohol. The nervous system is specially subjected to the influence of cold; the senses frequently act irregularly, giving rise to noises in the ears, and spectral visions; delirium often supervenes, and, finally, an irresistible tendency to, and desire for sleep, takes complete possession of the frame. Further exposure to cold, then produces a fatal coma. Isolated examples of death from this cause happen in the experience of civilized life; but large numbers of troops, and even entire armies, especially when ill-fed, clad, and protected, have been lost from the injurious effects of extreme cold. The effect of cold is most marked when the body itself is motionless. Its evil or fatal effects occur more rapidly, however, when the atmosphere itself is in motion; because, then, fresh quantities of cold air are brought continually in contact with the body, and so conduct away its heat more rapidly. A moist atmosphere is also detrimental, on account of its being a better conductor than dry air.

The *local effects* of extreme cold are usually manifested, first upon parts unprotected by covering, or most distant from the centre of the body, such as the feet, hands, face, or ears, and especially the nose. In such case the skin first becomes red from congestion of the dilated small arteries and capillaries, next it becomes blue from arrest of the circulation, and afterwards of a tallowy white, from the extreme constriction of the arteries supplying the part, so that the circulation is first retarded and then entirely arrested. In perfect congelation minute particles of ice actually form in the tissues. The congealed tissues may sometimes be restored to their normal state, provided that the return to a higher temperature be gradual, as is often and best accomplished in extreme cases of *frost-bite* by friction with snow or ice-cold water. By warming the frozen parts too rapidly, the gases of the blood and tissues, set free at the moment of congelation of the water, are expanded in the interior of the capillaries, or amongst the fine structural elements of the tissues, bursting the former or destroying the latter, and so inducing *gangrene*. In fatal cases of exposure to cold, the body may not, or may, be completely frozen, for the process of congelation of the water in the tissues may penetrate through the whole dead body; but death long precedes such a result, owing, on the one hand, to the fatal benumbing influence of cold on the nervous system, and, on the other, to the retention of some of the proper heat of the body, after actual death.

Effects of Heat on the Human Body.

These are also of great interest. In resisting moderately high temperatures, the problem to be solved is that of maintaining the temperature of the body, within 2°, or at most 5°, of its ordinary standard, at a time when it is not only producing heat within itself by its vito-chemical actions, but is also, like any other material mass, receiving heat from a surrounding medium hotter than itself. Thus, the *mean* daily temperature of the air, in the tropics, during the six summer months, ranges as high as from 80° to 90°, in the shade, the *highest* daily temperature in the shade varying from 104° to 118°, and the lowest nocturnal temperature ranging from 60° to 66°, the heat thus exhibiting a variation of from 44° to 52° in the course of 12 hours. In exceptional seasons, the highest temperature rises to 130°. Again, in the direct rays of the sun, the heat is, of course, still greater. The effect on the system is aggravated by motion of the hot air. The adaptability of Man to extremes of temperature enables him, however, to live in such a climate.

The chief means of maintaining the normal temperature of the body, in hot climates, consists in a large increase in the amount of the water exhaled from the surface of the lungs and of the skin, especially, however, from the latter. The skin becomes bathed with fluid, the evaporation of which, at the high temperature of the surface and of the surrounding air, occasions a loss of heat and a reduction in the temperature of the evaporating surface. In this way chiefly, the heat of the body is lowered, and maintained nearly at its normal standard. The effect in reducing the temperature of the body is greater, if the atmosphere be dry as well as warm, and then, also, if it be in motion; these conditions favor cutaneous exhalation and evaporation.

It has been shown, by an ingenious experiment, that the evaporation from the surface of the skin of the living frog subjected to high temperature, is sufficient to maintain the temperature of the animal at a stationary point, after it has reached a certain height; whereas moist mushrooms, subjected simultaneously to the same conditions, soon obey the temperature of the surrounding air. The frog and the mushrooms were placed in a chamber filled with dry air, heated from 122° to 140°; at the end of a quarter of an hour, both the frog and the mushrooms were nearly at an equal temperature, viz., from 62°

to 72°, each having, by simultaneous evaporation into the hot air, maintained a comparative coolness. As the experiment proceeded, the temperature of both rose to about 100°, at which point the frog's temperature remained stationary, while that of the fungi, no longer able to undergo further evaporation, continued to rise. The continuous exhalation from the moist skin of the frog was the only cause which could explain the non-occurence of a further rise in its temperature. (De la Roche and Berger.)

The effect of evaporation, in reducing the temperature of the living body, may also be illustrated by the results of experiments made on sponges wetted, and porous vessels filled with *hot* water, and placed in a dry oven, in which the air was still *hotter;* these bodies actually lose heat at first, evidently owing to temporary evaporation.

It has been supposed that the living animal body may possess special means of resistance to external heat, but of this there is no proof whatever. It may be entirely explained by the effects of evaporation.

Thus, when the surrounding air is warm or hot, especially if it be dry, the evaporation from the skin is increased, and so the temperature of the body is lowered; whereas, in colder air, especially if this be also moist, the diminished amount of evaporation tends so far to conserve the animal heat. The increased perspiration excited by the great heat of the skin furnishes, for a certain time, sufficient material for evaporation. There is a limit, however, to the amount of this excretion, and also to its rapidity of evaporation; for when the surrounding air becomes moist, a check being put to the evaporation, the body is no longer thus defended, and its temperature begins to rise. Thus, in a room, the temperature of which was 260°, and the air dry, it was found possible to remain for 8 minutes, by which time, the body was not much elevated in temperature, although the clothes, and other articles in the room, became very hot. (Blagden and Banks.) A case is on record of a person remaining 10 minutes in a dry hot air-bath at 284°; whilst Chabert, the so-called fire-king, went into ovens heated from 400° to 600°; but of course, for a much shorter period. Many workmen employed in foundries or glass works also withstand very high temperatures, the skin being profusely bathed with perspiration; these men of necessity drink large quantities of fluid. When, however, the air is moist as well as hot, the temperature that can be endured is much less; for, in a vapor bath, at a temperature of only 120°, the body rapidly gains heat, as much as 70° in 10 minutes, and a feeling of great and insupportable discomfort is experienced. (Berger and De la Roche.) It is said, however, that, from habit, the Finns can withstand, for upwards of half-an-hour, moist air or vapor baths gradually raised to 158°, or even 167°. Animals surrounded by air heated gradually to 200°, speedily die, their temperature being then raised about 13° above their natural standard. (The same authorities.) This seems, accordingly, to be the extreme limit of heat endurable by a warm-blooded animal. Most cold-blooded animals are killed by a temperature of about 75°.

In civil life, even in temperate climates, direct exposure to the rays of the sun is often fatal, producing some profound disturbance of the nervous centres, caused either by congestion of the vessels of the brain, owing to quickening of the circulation, or, as some have supposed, by expansion of the blood, from the heat acting on the contents of the skull, the capacity of which is unchangeable. This *coup de soleil* occurs still more frequently in the tropics, amongst troops on the march, or amongst coolies or slaves working on railways or plantations. In Pekin, during about ten days in July, 1743, the thermometer stood at the extreme height of 104° in the shade, and in that period 11,400 people died. Under extreme elevations of temperature, the only safety consists in retiring to the protection of houses, and in reducing the temperature of the atmosphere in them by artificial methods, such as by the use of large fans or punkahs, wet hangings, and other means. Habit accustoms the Chinese, negroes, and others, to bear a greater heat than the natives of temperate climates can support.

Theories of Animal Heat.

Previously to the time of Lavoisier, the heat of the body was more or less vaguely referred to friction, the organic processes of nutrition, the influence of nervous action, and generally to what was understood as the action of the so-called vital force.

In consolidating the discoveries of his predecessors, in regard to the chemical nature of carbonic acid, oxygen, and nitrogen, and in explaining therefrom the chemical processes and products of respiration, Lavoisier propounded, for the first time, a distinct scientific theory of the production of animal heat. This, now known as the *chemical theory of animal heat*, regards this heat as the result of an oxidation or combustion process, affecting the animal frame. Carbon, when heated in the presence of oxygen, unites with that gas, forms carbonic acid, and evolves heat. In like manner, Lavoisier argued, that the formation of carbonic acid in the blood, as the result of respiration in living animals, must be accompanied by an evolution of heat.

Though Lavoisier was wrong in supposing that this union of oxygen with carbon takes place in the pulmonary capillaries, nevertheless, his chemical theory of respiration is, with certain modifications and extensions, accepted as the true theory of animal heat.

To found this theory of respiration it was necessary to compare the amount of heat evolved, during the direct combination of a certain quantity of oxygen and carbon out of the body, with the amount of heat given off from a living animal during its consumption of a similar quantity of oxygen. This inquiry was surrounded by many difficulties.

To obtain data for these purposes, Lavoisier made the first step in the science of *calorimetry*, by burning given quantities of carbon and hydrogen, in his so-called *ice calorimeter*. This was a closed metal case with double sides, between which ice was packed; the source of heat to be subjected to experiment was placed in the interior of the case, and the quantity of heat given off was estimated by the quantity of ice which was melted. The *water calorimeter* of Count Rumford is constructed on a similar plan, but is filled with distilled water of a known temperature, and measures the quantity of heat given out in the experiment, by the elevation of temperature of a known quantity of water.

In the first accurate experiments on animals which were made by Dulong and Despretz, a water calorimeter was employed. The animal was placed in a metal chamber, which was surrounded by a given quantity of water inclosed in a still larger vessel; air was conducted to the internal chamber by one tube, whilst a second long spiral tube passing through the water, like the condensing tube of a still, conveyed away the warm air, which, before it escaped, gave up its heat to that fluid. The stream of air was rendered uniform by an apparatus known as an *aspirator*, a large closed vessel filled with water, and connected with the free end of the coiled air-tube, so that on the gradual escape of the water from the aspirator, through a stop-cock, air was drawn through the apparatus at a uniform rate. In the water of the calorimeter itself, a moving fan agitated the fluid, so that its temperature was kept uniform during the experiment. Lastly, the air, as altered by the respiration of the animal, or a part of it, the rest then being measured, was analyzed, in order to determine the quantity of carbonic acid produced. It was, at that time, erroneously supposed that this corresponded exactly with the quantity of oxygen consumed. Rabbits or dogs were subjected to experiments, varying from an hour and a half to two hours' duration; and the results obtained by Dulong and Despretz, showed that the amount of heat given off was from $\frac{1}{5}$th to $\frac{1}{4}$th more than the quantity of carbonic acid produced would account for. In subsequent experiments, made by Despretz alone, it was found that from $\frac{1}{4}$th to $\frac{1}{10}$th of the heat was thus unaccounted for.

The excess in the heat actually produced by the animals experimented on, was supposed to be accounted for, by the friction of the heart and the muscles, by that of the blood in the vessels, by the disengagement of heat taking place in the conversion of fluid into solid matter in the nutrition of the tissues, and by some possible action of the nerves. It has, indeed, since been shown, that heat is really given out in muscular contraction. Nevertheless, these supposed causes of animal heat are not primary, but secondary causes. The heat given off in muscular contraction, is itself engendered by oxidation in the blood of a muscle, or in the muscle itself, during the so-called parenchymatous respiration. The heat produced by mere friction in the body, must have its source in muscular contraction, and this, as we have just said, is due to chemical change or oxidation. The conversion of fluid into solid substance, in the nutrition of the tissues, is, as will be presently explained, an apparent, and not a real cause of internal heat; and lastly, any influence of the nervous system is indirect, operating only by exciting organic processes, themselves involving oxidation.

The deficiency of heat-producing power in the quantity of carbonic acid given off by the animals experimented upon by Dulong and Despretz, in comparison with the heat which they simultaneously evolved, may be otherwise accounted for. In the first place, these observers did not determine the temperature of the animals before and after each experiment, which might have shown some *retention* of heat. But other points are of more moment. The modern researches of Favre and Silbermann, prove that the heat evolved by carbon in its combustion, is greater than that estimated by Dulong and Despretz. It is now known, that more oxygen is absorbed in respiration, than is returned in the form of carbonic acid, and this oxygen doubtless is also combined in the system, partly with hydrogen, and partly with sulphur and phosphorus, in either case evolving a certain amount of the heat of chemical combination. The hydrogen of the carbhydrates being already associated with oxygen in the proportions to form water, is not supposed to be able to give out further heat; but some of that contained in the fat and albuminoid bodies, must be oxidized in the system, as was first suggested by Barral, though much of the hydrogen of the nitrogenous substance, appears in the urea. The larger part of the heat is, however, due to the oxidation of carbon in the system. The nitrogen is never oxidized, but passes out almost entirely in the form of urea, and supplies no animal heat. Experiments have shown that carbon, in different states of aggregation, yields slightly different quantities of heat in being burnt, wood charcoal giving out more heat than the more compact coke. The combination of carbon and hydrogen in the animal economy, is not like that which occurs in artificial combustion, simple and *direct*, but complex, and marked by intermediate decompositions, and most varied products. By many, it has been supposed that these conditions might modify, in some way, the quantity of heat evolved; but it seems more probable, that no number of intermediate stages of decomposition can alter the total quantity of heat given out; and that, according to the degree of oxidation which occurs, the same amount of heat is evolved, whether this be direct and rapid, or complex and slow. Such decompositions in the body may affect the amount of heat evolved in *particular organs* or parts of the system, as in the liver, kidneys, or the muscles when in action; but they cannot modify the ultimate or *total* heat product. It has even been conjectured that the oxygen of the atmosphere used in respiration, being partly ozonized, might evolve a larger amount of heat than in ordinary combustion; but the same air is employed in both cases.

The idea entertained by Dulong and Despretz, that a balance of heat might be evolved in the conversion of fluid into solid substances during the act of nutrition, has been mentioned as fallacious. If, indeed, new nutrient matter be solidified in the act of deposition, the process of disintegration of tissue which precedes or accompanies this, implies a precisely similar amount of liquefaction which would involve a disappearance of heat. In the digestive and secretory processes, too, the numerous acts of liquefaction imply absorption of heat. Bertholet has recently advocated the view, that *molecular* as well as chemical changes in the body, may give rise to heat. The mode in which a particular, complex, organic compound splits up, may influence the amount of heat which it gives off, and, *locally*, this would affect the temperature; but there is a balance in these actions, and the *total* result is that of simple change. Certain processes of *hydration*, or the assumption and *fixation* of *constitutional water*, which are supposed by Bertholet to be constantly occurring in the system, and to be the actual cause of animal heat, may likewise produce *local* evolutions of heat. The formation from starch, of sugar, lactic acid, and oxalic acid, imply successive acts of hydration, and so perhaps also do the changes of albumen into gelatin, glycocoll, creatin, creatinin, and urea. But a certain quantity of oxygen actually disappears in the body, and two of the chief ultimate products of excretion, carbonic acid and water, are *oxidated*, not simply *hydrated*. Urea alone can be considered such a product, being of course imperfectly oxidized. The supposition that hydration will explain the formation of all the animal heat, overlooks the far larger amount of heat evolved in the ultimate *oxidation* of the carbon and hydrogen, which leave the body as carbonic acid and water; nor does it explain the higher temperature of those animals which consume a large quantity of carbon and hydrogen in their food.

With regard to the human body, the estimates of Despretz were made on the supposition that a Man, according to his weight, expired seven times as much carbonic acid as the dog experimented on by him. The quantity thus arrived at is much less than that computed by all subsequent experimenters, being only equivalent to $5\frac{1}{2}$ oz. of carbon in the 24 hours. Other observers have estimated the daily excretion of carbon in the form of carbonic acid, as 8 or 9 oz. The size or weight of these persons has not been recorded. Vierordt's estimate in a number of individuals of different heights ranges from 5 to 8 oz. In men of a mean height of 5 feet $9\frac{3}{4}$ inches, Dr. Edward Smith estimates the quantity at upwards of 7 oz. The calculations hereafter given for a person 5 feet $6\frac{1}{2}$ inches, yield a quantity somewhat exceeding 6 oz. of carbon per day. These results are obtained by direct experiments on the absolute quantity of carbonic acid expired by animals or Man. Liebig's estimate is still higher; thus, the quantity of carbon in the daily food being determined on the one hand, and that contained in the urine and intestinal excretions on the other, the difference, which was taken to represent the amount given off by the lungs and the skin together, amounted to 13.9 Hessian ounces, or to upwards 15 oz. av., of which $\frac{1}{2}$ oz. might be exhaled from the skin, and $14\frac{1}{2}$ oz. from the lungs. This large quantity was found in vigorous soldiers actively exercised in the open air, and supplied with abundant food. In other examples, viz., in prisoners compelled to labor, the quantity was about $11\frac{1}{2}$ oz. av.; whilst in a prison where no forced labor was practised, it was about $9\frac{1}{4}$ oz. av. Similarly estimated, the carbon expired daily by sailors in the Danish Navy was found to be about $10\frac{1}{2}$ oz. av. (Scharling.) These results taken generally, so far confirm the chemical theory of animal heat, that they nearly explain the deficiency of $\frac{1}{5}$th or $\frac{1}{4}$th left by the daily combustion of $5\frac{1}{2}$ oz. of carbon, calculated to be eliminated by Despretz; the excess of oxygen absorbed which unites with hydrogen, and to a small extent with sulphur and phosphorus, may explain the rest.

The chemical theory of the production of animal heat by oxidation is in harmony with the fact, that increased respiration increases the amount of chemical decomposition in the body, and simultaneously, the amount of heat produced. Thus, all the conditions connected with *age, sex, period of the day* and *season*, as well as those relating to *food*, whether in excess or deficiency, or whether absolutely withdrawn, as in starvation, and to *exercise* (pp. 842–847), which increase the activity of the respiration and the amount of carbonic acid given off, raise the temperature of the body; whereas all those which diminish the respiratory actions and their chemical products, lower that temperature. The relations, as to respiration and temperature, in the lower animals, confirm this view. It has been objected, that not only the respiratory function, but all the other functions of the body, are similarly modified under the above-named conditions; and that, therefore, the variations of temperature may be referable to other processes as well as to the respiratory interchanges. But since no function of the body whatever, whether it be that of sensation, the guidance of motion, motion itself, nutrition, secretion, or any other function, can be performed without concomitant changes in the chemical molecules of the tissues or organs concerned, and as all these changes are but steps or stages towards a more or less complete oxidation, so any production of heat by them must ultimately be referred to this chemical action. According to any other view the heat would be produced from nothing, or without that accompanying conversion or change in the condition of force and matter, which we now know is necessary for its production.

The Cold-blooded animals expire but small quantities of carbonic acid, and their respiration is feeble; whilst opposite conditions are noticeable in the Warm-blooded animals. The most active of these latter give off more carbonic acid, and manifest a higher temperature, the Carnivorous Mammalia being, in both these respects, above the Herbivorous, the smaller quadrupeds above the larger ones, and, as a Class, the Birds above the Mammals. The relative complexity of the pulmonary organs, the extent of the respiratory surface for the exposure of the blood in the capillaries, and the contrivances for the more frequent renewal of air in the air-cells, keep pace with the increase of temperature in the animals themselves. In the hottest animals known, viz., Birds, special peculiarities exist in the air-cells, and the air-cavities in the bones, with which are associated great force of the heart, great rapidity of its action, a high rate of motion of the blood through the capillaries, a large number of red blood corpuscles, a small amount of evaporation from the skin, and a solid condition of the urinary excretion, involving less loss of heat in its production than if it were fluid. The urinary products of Birds are, moreover, chiefly composed of urate of ammonia, which contains less oxygen than urea, so that more of that element passes off as carbonic acid. (J. Davy.)

The importance of the relation between the quantity of the red corpuscles in the blood, and the temperature of the body, is illustrated by the following numbers, which show the quantity of dried solids of the clot, in 1000 parts of blood, in a series of animals belonging to the several Classes of the Vertebrata. The hen, 157.1; the dog, 123.8; the tortoise, 80; the frog, 69; and the eel, 60 parts in 1000. (Prevost, Dumas, J. Marshall.)

Animal heat being regarded as the result of a process of oxidation, the small amount generated by the Cold-blooded animals may be supposed to be derived from the metamorphosis of their own tissues or blood. The same may be true as regards the large Carnivorous animals, the active habits of which, in high external temperatures, may furnish sufficient oxidizable material in the metamorphosed blood and muscular and nervous tissues, to maintain the temperature of their bodies; but Carnivorous animals consume also large quantities of fat, proportionate, it may be remarked, to the coldness of the climate in which they live. In warm climates, Man also might thus sustain his temperature; but in colder regions, where the loss of heat from the body is more rapid, Man, like the Herbivora, whose habits are inactive, must rely upon food also, as one source of oxidizable material; and, like them, upon food containing more carbon and hydrogen, and proportionally less nitrogen. In different persons, and in different seasons and climates, the extent to which carbonaceous and hydrogenous food is relied on, as a source of combustible material, may vary. An elevation of the external temperature will lessen the amount of oxidized food; whilst the opposite condition increases it. The excess of carbonic acid exhaled in cold seasons, can only be accounted for by its proceeding from the greater quantity of food then consumed. On these principles may be explained the fact, that no one dietary is economically adapted to all constitutions, occupations, habits, races, seasons, or climates; hence, the laborer requires a different diet to the sedentary student, and the native of the tropics different food to the Laplander.

Influence of the Nervous System in the production of Animal Heat.

This was formerly greatly exaggerated, and was attributed to some direct action of the so-called nervous force. Many researches upon animals have shown that injuries to the brain, whether by sections, or by the administration of narcotics, are followed by a lowering of the temperature of the body. (Brodie, Legallois, Wilson Philip, Hastings, C. Williams, and Chossat.)

In paralysis, from cerebral disease in Man, the paralyzed limbs are usually of lower temperature than the sound limbs, the difference sometimes being as much as 7°. On the other hand, an elevation of temperature in certain regions may follow local injuries of the nervous system. Thus, when the spinal cord is divided in the middle of the back, in a Warm-blooded animal, the lower half of the body may become warmer, and remain so for some time. In complete paralysis of the lower half of the body, in Man, from injury of the cord, a similar increase of heat has been observed in the groin, viz.: 111°. (Brodie.) Besides these facts, there are many which show that general depressing causes, acting on the nervous system, lower the temperature, whilst excited conditions of that system are accompanied by increased animal heat—for example, exhaustion or fear on the one hand, and strength or passion on the other. In the last instances the influence of the nervous system is plainly indirect, and must be attributed to a corresponding diminution or increase of the pulse and respiratory acts. The ultimate influence of alcohol, in raising the temperature of the body, may also be partly due to its specific stimulating effect on the nervous system, and, through it, on the heart and respiratory organs;

but it may also yield a ready fuel or combustible substance, easily absorbed into the system and easily oxidized in it; these two last-named qualities may account for its great use in cases of exhaustion from fevers. Again, when the sympathetic nerve is divided in the neck of an animal, or its chief cervical ganglion is removed, the temperature of the whole of that side of the face may rise even as high as 11° above its normal standard; and this may continue for months with increased sensibility and increased color from vascular congestion. In such a case, when the distal end of the cut nerve is galvanized, the temperature for a time falls. (Bernard.) The elevation of local temperature is also believed to be an indirect effect, and to depend on an increase in the flow of blood to the part, consequent upon a relaxation of the walls of the smaller arteries, owing to the loss of controlling power on the part of the vasi-motor nerves (p. 308). Serious injury, or disease of the spinal cord may act in the same way, because the sympathetic system has connections with, or origins in, it (p. 309). The lowering of the temperature, after destruction of the brain, which continues in spite of artificial respiration,—not performed too rapidly, so as to cool the animal by that very process (Brodie), but more slowly (Wilson Philip and Williams),—has also been, of late, most frequently attributed to the loss of some indirect influence of the nervous system over the strictly chemical heat-producing changes in the system, whether of respiration, nutrition, or secretion. Lastly, it has been suggested that heat may be directly produced in the nervous substance itself, owing to the rapid metamorphoses to which it seems liable in its healthy and active condition, or else to some transformation or passage of its ordinary force or mode of action into a calorific action producing heat, in the same manner, as in the electric fish, it may be converted into electricity. (Carpenter.) The nervous substance must be decomposed in all cases in which it is in action, especially during exercise, when it controls the muscular movements; much movement always produces heat. In such instances, and also in psychical acts, the nervous substance is directly oxidated; so that, ultimately, the animal heat evolved is the result of chemical action.

That the nervous system is not essential to the production of heat in living organisms, seems to be shown by the facts, that in many of the lower animals no traces of a nervous system have yet been discovered, and, that in certain processes of vegetable life, as in the fertilization of the ovule, and in the commencing stages of germination, heat is also evolved. When, however, in animals, that system is present, it is endowed with such power of control over all the functions generally, and exhibits such innate activity, that it determines and excites waste in other tissues, and undergoes waste in its own, thus indirectly or directly contributing to the production of animal heat.

Uses of Animal Heat.

The modes in which the heat of the body is expended are several. First, it supplies the constant *loss of heat* from the body, by radiation and conduction to the clothes or other surrounding objects or media, when, as is usual, these are cooler than the body. It also furnishes the heat necessary to *vaporize* the water of the cutaneous and pulmonary exhalations; it warms the air expired from the lungs; it heats the secretions as well as the body itself; and, lastly, it warms the food and drink taken into the body, when these are cooler than the internal organs, and aids in the solution of digestible substances, and in their metamorphosis for the purposes of absorption. Of 100 parts of heat given off by the body, 72.9 are lost by radiation from the surface, 14.5 by evaporation from the skin, 7.2 by evaporation from the lungs, 3.5 from warming the air used in respiration, and 1.8 by the urine and solid excreta.

As the standard of temperature remains constant within 2° or 3°, between hot and cold seasons, and Tropical and Arctic climates, the quantity produced in the body depends on the external temperature, and must be greater in cold climates, in which the loss is greater, than in warm climates. The amount required to be produced is also modified by the degree of protection of the body, either by shelter or clothing.

Hibernation.

Amongst the most remarkable phenomena presented by animal life, in the temperate and cold regions of the earth, are those which are known under the name of *hibernation.* During the winter season, a few Mammalia retire into burrows or other shelter, and there, either under the influence of the low temperature, or guided by an inherent instinct or an acquired feeling, pass into a condition of torpor much more profound than ordinary sleep. The marmot, dormouse, and hedgehog, are the most familiar examples of this hibernation in the *Mammalia.* It is remarkable that no *Birds* are known to hibernate, the belief once prevalent that swallows retired to the bottom of ponds to hibernate, being erroneous. Amongst *Reptiles*, both serpents and snakes, as well as land-tortoises, hibernate; and in the *Amphibia*, the frogs and newts. Both serpents and frogs have been kept in this condition, by artificial cold, for three years. Hibernation in Fishes is not known, unless it be compulsory from freezing of the water. Of the *Non-vertebrate* animals, only terrestrial species are known properly to hibernate, such as the land-snails and slugs amongst the *Mollusca*, and the chrysalides of certain *Insects*, which pass through a winter, before they change into the imago state. Even in the *Protozoa*, examples are met with, of a winter state or condition, in which those animals undergo the process known as *encystation*, so called because in it, they surround themselves with a protective *cyst*, in which they remain dormant, until the return of warmth induces peculiar changes in them, for the reproduction of new animals.

The condition of partial hibernation manifested by certain animals, which collect a store of winter food, such as the *beaver* and others, is named *spurious hibernation.* In this state, the circulation and respiration are not so diminished in activity, nor the temperature so reduced, as in true hibernation; for though the animals sleep much, they, from time to time, arouse themselves to take food.

In the true hibernating Warm-blooded animal, not only the nervous and muscular systems are quiescent, but digestion entirely ceases, no food being taken. The circulation is very slow; the respiratory movements are almost, or according to some, completely arrested; the interchange of oxygen and carbonic acid in the air-passages, can take place by diffusion only; the absorption of oxygen and the evolution of carbonic acid, are very slight, and the animal heat accordingly sinks; so that, without protection from the cold of the winter season, the animal would die. The respiration which continues is supported by a store of fat, which serves as fuel during the dormant state;

when the creature is roused from this condition, by any irritation, by heat, or by great cold, distinct respiratory movements take place, the heart's beats are quickened, and it manifests increased activity. If the animal be aroused by extreme cold, it soon becomes still more torpid, and may even die if the low temperature be long continued. If excited too completely by warmth, it is also apt to die, unless provided with suitable food, and carefully maintained at a moderate temperature. The suspension of animation in Reptiles and Amphibia, is still more complete; but probably even here some vital action goes on. In many instances, in the lower Non-vertebrate animals, it is probable that all the organic processes are, for a time, completely suspended, as, *e. g.*, when they are almost frozen, or first dried and then frozen.

In the Animal Kingdom, considered generally, we observe that a high temperature of the body not only increases the activity of the various functions, but that this very activity produces, in its turn, a demand for increased respiration, and so engenders an increased amount of animal heat. In the case of Cold-blooded animals, also, an elevation of the temperature of their bodies, by external heat, increases their activity and their demand for increased respiration; and, accordingly, it is found that in Reptiles more carbonic acid is given off in high temperatures, a result opposite to that which takes place in Warm-blooded animals, and in Man. The respiration of Warm-blooded and Cold-blooded animals is said also to differ, if not absolutely, at least relatively, in this particular: that it is only in the Warm-blooded creatures, that some portion of the food, when absorbed into the blood, is devoted at once to respiratory purposes, forming, as it were, fuel immediately destined for the production of heat by oxidation, without having previously entered into the tissues; whereas, in the Cold-blooded animals, the tissues only, and not the food merely assimilated into the blood, except perhaps in exceptional cases, and then in a far lower degree, are oxidated, and so produce a small amount of animal heat. In the Warm-blooded animals the blood-corpuscles are much more numerous, and the quantity of carbonic acid excreted is much greater, than in the Cold-blooded species.

Spontaneous Combustion.

The highest natural temperature attained, in the healthy state, by any animal, is that noticed in the swallow, about 111°; the highest temperature observed in the healthy human body, is 102°; and in disease, 111°. Moreover, experiments have shown that an increase of 13° in the temperature of the body of one of the Mammalia, is fatal. It is obvious that the highest of these temperatures is entirely inadequate to set on fire the animal tissues; it is even insufficient to inflame the vapor of alcohol. It is therefore, impossible to believe that the body of a drunkard, whose blood and tissues may even be supposed to be saturated with alcohol, or with some of the products of its decomposition, could spontaneously burn; for the temperature of ignition of the tissues, or of such compounds, is much higher.

Of the so-called cases of *spontaneous combustion*, not one has actually been seen to happen. Naturally, no eye-witness is present, but the more or less consumed body is found; and such occurrences usually take place in persons addicted, during their life, to habits of intoxication. The event is rendered marvellous by the supposition of a spontaneous process of combustion. Of the possibility of burning the dead body with a due amount of heat, or even parts of the body before life in the remainder of it is entirely extinct, there is no doubt, the sensibility being supposed to be deadened by excessive alcoholism. But the heat, necessary for this combustion, is far greater than is gener ally supposed. It is extremely difficult to burn a dead body. That the presence of alcohol in the blood and tissues would increase the inflammability of the dead or dying body, is possible. The commencement of the combustion is clearly to be looked for in external, not in internal causes. In all recorded instances, these cases have happened either in the night, or at other times when fire, candles, or matches were present, or might be supposed to be present; for frequently the evidence of this may be destroyed by the spread of the combustion itself. On the whole, it is rational to conclude, more especially as habitual drunkards are incapable of exercising care in regard to these sources of danger, that they have themselves, in a state of intoxication, set fire, in falling, or otherwise, to their clothes or other combustible materials, or that they have been reached by flames, otherwise occasioned by the falling of candles, or by the emission of sparks from the fire. It is significant that no case of spontaneous combustion has ever happened in an animal.

EVOLUTION OF LIGHT.

A few examples are on record of the evolution of *light* from certain excretions or discharges from the living human body; but most of these instances have been observed in diseased and dying persons. The perspiration after violent exercise, in one case, and the urinary excretion in several instances, have been seen to display a decided luminosity; in the former case the luminous matter being even transferable to the clothing. In three instances of persons in the last stage of phthisis, a light, owing apparently to luminous breath, has been noticed playing about the features; the surface of a cancerous ulcer is also said to have exhibited a similar appearance. In these cases, the light is supposed to proceed from the slow oxidation of phosphorus or of some phosphuretted compound, resulting from the incipient decomposition of the excretions, or from their containing some imperfectly oxidized compound of phosphorus, which had accumulated in the blood, and become eliminated in those fluids, but which would ordinarily be thrown off, in the shape of alkaline or earthy phosphates. Phosphorus dissolved in oil, injected into the veins of a dog (p. 828), produces a luminous condition of the breath; and a luminous state of the urine has been observed in men who have taken phosphorus medicinally. It has been suggested that, as a large number of the cases of luminous breath in men have occurred in persons addicted to excessive drinking, certain bodies, derived from the decomposition of alcohol, may impede the proper oxidation of the phosphuretted compounds, which then escape in the breath or other excretions. It is even presumed that the presence of such compounds in the blood may impart an unusual degree of combustibility to the body. But the known compounds derivable from alcohol, even aldehyde, are not so readily oxidizable as the imperfectly oxidized compounds of phosphorus. This explanation is therefore speculative; and the so-called cases of spontaneous combustion of the bodies of intemperate persons, as just stated, are unfounded, and capable of explanation on other and simpler grounds.

Dead animal matter is frequently *luminous* or *phosphorescent*. The surfaces of the muscles and other soft parts of bodies undergoing dissection in anatomical schools have sometimes been seen to emit a brilliant light; and luminous exhalations from graveyards, especially from the recently exposed soil, have not unfrequently been observed. The remains of decaying animal matter generally, may also become phosphorescent; but this more particularly happens in the case of marine Fishes and the marine Mollusca, Crustacea, and Cœlenterata. This is also at present attributed to a true phosphorescence, some imperfectly oxidized phosphuretted compound being supposed to be the result of an incipient stage of decomposition. It disappears on the occurrence of actual putrefaction.

The warm-blooded Vertebrata apparently possess even less power than Man, of evolving light from the living body, or authentic cases of such an event would have been recorded. The light seen in the eyes of the cat and other creatures in the dark, is merely a reflection from the iridescent portion of the choroid coat within the eyeball. Amongst the cold-blooded Vertebrata, the gray lizard is said to deposit eggs which are sometimes luminous; and a species of frog in Surinam, is described as emitting light, especially from the mouth. Certain cases of luminosity amongst marine Fishes, may be owing to the agitation and percussion of smaller luminous animals in the water; but a marine species of Scopelus, allied to the Salmonida, is said to emit stars of light from the body and head; it is in one of these fishes that Leuckart has recently described scattered organs, containing lens-like bodies, which are regarded by him as eyes (p. 477). These may be light-reflecting organs.

The most remarkable and characteristic examples of the emission of light from the living animal body, occur amongst the Non-vertebrate creatures. Some of these are met with in *air-breathing* animals. Thus amongst the *Annulosa*, two families of Coleopterous insects or beetles, viz., the Elaterida and Lampyrida, furnish us with the well-known examples of the fire-flies and glow-worms. The fire-flies proper to hot climates, give out a very brilliant light from two spots, one on each side of the thorax, and from a third, on the under side of the same part; the light is present in both sexes. In the glow-worms, however, the light is softer, and though observed in the male, and, even more feebly, in the chrysalis, in the larvæ, and in the egg, it is decidedly more striking in the female; it is also chiefly observed at particular seasons. It proceeds from the under side of the three last segments of the abdomen. Examined under high magnifying powers, the luminous patches are seen to consist of little sacs, containing a yellowish granular matter, which is the luminous substance. These sacs are closed by horny lids, having peculiar flat surfaces, suited to the diffusion of the light; the granular matter and sacs are traversed by numerous air-tubes, or tracheæ. The light is given out, even after the segments are removed from the rest of the body, and luminous streaks may be produced by rubbing the yellow matter between the fingers. There seems no doubt that the cause of the luminosity, is the feeble combustion of some organic compound excreted by the animal. It is said, however, not to contain phosphorus in any appreciable quantity, and the product of its combustion is carbonic acid. (Matteucci.) Other alleged instances of luminous winged Insects are doubtful. Amongst the Annulosa, some Centipedes, and, under certain circumstances, the common earth-worm, also present examples of luminosity. Amongst the Mollusca, there are luminous air-breathing Gasteropods.

By far the larger number of luminous Non-vertebrate animals, is found amongst the aquatic breathers, and exclusively, perhaps, amongst the marine species. Of the Molluscous marine animals, the Cephalodopous Octopus, the Pteropodous Cleodora, and the Lamellibranchiate Pholas, exhibit luminosity. Many Molluscoid animals, but especially the Tunicated Salpida and Pyrosomida, are eminently distinguished for this property. Again, many minute marine Crustacea appear like little luminous specks in glasses of sea-water, especially when this is agitated; and they are even discernible in the stomachs of larger Molluscoid animals, which feed upon them. Some of the marine Annelida are distinguished by being able to emit sudden scintillations of light along the body, which may be repeatedly excited by mechanical irritation. It has been suggested that, in these cases, the light may be excited through nervous agency, which may possibly undergo conversion into light. (Carpenter.) Amongst the Annuloid animals, certain Star-fishes are said to be luminous. But the Cœlenterata yield the largest number of luminous marine creatures, especially the Acalephæ and the Hydroid Polyps, such as Pennatula and others. Lastly, a minute jelly-like creature, formerly assigned to the group Acalephæ, amongst the Cœlenterata, but now classed amongst the Protozoa, by some as a Rhizopod, but by others as a peculiar and gigantic Infusorial animalculæ (Huxley), the *Noctiluca miliaris*, is the most common of all light-giving creatures in the temperate oceans, and is the chief cause of the luminous nocturnal appearance in our Northern Seas. In the Tropics, the phenomena is much more striking and brilliant, and depends upon a greater variety of animals, especially upon the Medusæ and the Hydroid Polyps.

The luminosity of these various marine animals is said to depend upon a mucous secretion from their integument, which will even impart luminosity to water or milk with which it is mixed. The so-called phosphorescence is always more marked in warm than in cold climates; it is increased by moderate elevation of the temperature of the water, and, most remarkably, by brisk agitation of the fluid, either because the secretion is detached from the animals, or simply owing to their excitement. The light is extinguished by extremes of either heat or cold; it disappears *in vacuo*, and is restored on renewed exposure to air; it is rendered more vivid by various stimulating substances, if moderately used, and also by electricity; but it is extinguished by the excessive employment of these, and especially by such vapors as those of ether and chloroform, which would interfere with oxygenation. Oxygen increases and maintains the phosphorescence; carbonic acid first excites, and then destroys the luminous property; sulphuretted hydrogen almost instantly arrests it. The luminosity may continue for a time after death, unless this has been produced by some specially poisonous substance. It entirely ceases as soon as putrefaction begins.

From the preceding facts, it is obvious that the luminosity of animals is owing to some living action, and not to decomposition.

Its use is by no means understood. The supposition that it serves occasionally to guide one sex to the other, affords a very partial explanation of the facts; for it does not apply to the cases of the multitudes of hermaphrodite marine luminous animals. It may conduce to their destruction, by assisting other animals in seeking them as food; or it may serve to illuminate deep waters. But this curious phenomenon affords a good example of the imperfection of our knowledge of *final causes.*

In the glow-worm it appears not to be phosphorus, but some carbonic compound which produces the light. Even in the case of the numerous marine luminous animals, it is not proved that the light is owing to the slow oxidation of a phosphuretted substance. This, however, seems more probable in the case of animals living in water, in which the luminous oxidation of a phosphuretted body is more conceivable than that of a hydro-carbonaceous substance. It is possible that some, at least, of the feeble light exhibited in these phenomena, or its intensification, is due to *fluorescence* developed in a high degree; fluorescent substances certainly exist in living animals. The term phosphorescence must be regarded as descriptive and provisional only, for the light may not depend in any case upon the oxidation of a phosphuretted compound.

The evolution of light from these animals as a normal phenomenon, and that from the human body as an occasional or morbid occurrence, must be accompanied by chemical change, in which the chemical energy passes into the form of light. The photic work of the animal body must therefore depend on the chemical energy evolved by it. But the quantity of matter subjected to change in its production is very small.

EVOLUTION OF ELECTRICITY.

The electric currents constantly present in the living nervous and muscular tissues, and the common electric current present in the entire human body, and in the bodies of the lower animals generally, especially noticeable in the frog, have been elsewhere mentioned (pp. 138, 224). This common current usually passes from the lower extremities to the head of an animal; but in the upper limbs of the human body it is said to be directed from the shoulder to the fingers. Electric currents have also been detected upon different secreting surfaces and glands, and even between a secreting membrane and the veins returning from it. These phenomena cease with the life of the animal experimented upon. The direction of these currents is shown by delicate galvanometers. Thus, currents pass from the venous blood, which is positive, to the gland or secreting surface, which is negative; no current passes between a gland and the arterial blood. Arterial blood is said to be positive as compared with venous blood. (Scoutetten.) Between the corresponding points of the two sides of the body, or of opposite limbs, no electric currents are ordinarily found; but they occur between non-correspondent points, and even between corresponding points, if there is a difference with respect to their nutritive activity, as when one limb is at rest and the other in motion, or as when one limb is more or less inflamed. (Matteucci, Du Bois-Reymond.) The electricity of the human body under ordinary circumstances is rapidly conducted from it, and thus an equilibrium is maintained with respect to surrounding media. But when the body is insulated its proper electric state is speedily manifested, either when it is brought into contact with non-insulated bodies, the galvanometer intervening, or when two insulated persons are connected with the galvanometer or touch each other. Thus examined, the electric condition of men is usually positive, that of women is said more frequently to be negative. Sanguine and irritable persons exhibit a more active electric condition than others. It is well known that electricity is sometimes developed in the body by friction, or by the rapid removal of stockings, especially silk ones, or of other articles of dress which fit closely to the skin. This phenomenon is accompanied by slight crackling noises, and even by sparks, especially in dry weather, dry air being a better non-conductor than moist, and so preventing the escape of the electricity of the body. Remarkable and exceptional instances of the accumulation of electricity in the human body are on record, in which, if the person were only moderately insulated, sparks could readily be drawn from any part of the body.

The total quantity of electricity developed in the body must be very large; but owing to the quantity of water in the tissues, to the high conducting power of that fluid, and to the absence of arrangements calculated to insulate the electric currents, the electricity passes as soon as it is generated into a state of equilibrium. Moreover, this animal electricity speedily acquires a condition of equilibrium, as regards neighboring objects and media; and it is only when the body is more or less perfectly insulated, that other than static currents can be detected in it.

Similar electric currents exist in all Warm-blooded Vertebrata, and are probably universal in the Cold-blooded Vertebrata. In the frog they are remarkably strong, and the animal itself, so far as its muscular system is concerned, and probably also as regards its nervous system, is peculiarly susceptible to electric influences.

It is amongst the Cold-blooded Vertebrata only, and in the lowest Class of these, viz., in Fishes, that the singular power exists of generating and accumulating within certain organs, a large amount of electricity, which can be discharged from the body in the form of a shock, either involuntary, or apparently, also, at the will of the animal. Electric fishes are found in almost all climates; but they belong to different genera. There are eight species known at present to possess this power. Of these five are marine: three of these are Torpedoes belonging to the Ray family; they inhabit the Mediterranean and the Atlantic, and are sometimes even used as food. The fourth is the Trichiurus or Sword-fish of the Indian Seas. The fifth marine species is the Tetraodon, found amongst the Comoro Islands. The fresh-water or river species of electric fishes are the Silurus or Malapterurus, a salmon-like fish of the Nile, Niger, and Senegal rivers of Africa; the Momyrus, or Nile Pike, and lastly, the celebrated Gymnotus or Electric Eel, found only in the Amazon and other large rivers of South America.

In the Torpedoes, which are true flat fishes, the electric organs consist of two compressed oval masses, lying one on each side of the head, and reaching from between the gills into the body; they are supported in front and externally, by a cartilaginous border. They consist of a strong membranous investment, inclosing a soft pulpy structure, divided by septa into hexagonal columns, which have their ends directed towards the upper and under surface of the fish. Each column is subdivided, by delicate and extremely vascular partitions, into numerous separate cells, and each cell is filled with a clear fluid, of which $\frac{1}{10}$th part is albumen, with traces of common salt. Owing to the large proportion of water in them, the specific gravity of the electric organs is only 1026, whilst that of the body of the fish is 1060. These remarkable organs are supplied with very large nerves, larger than any other nerves in the body, and larger than any nerve in animals of the same size. The nerves arise from a special nervous ganglion, called the *electric lobe*, connected with the medulla oblongata, immediately behind the cerebellum; at their roots, these nerves have apparent connections with the fifth and eighth pairs; their finest branches end in close plexuses, upon the delicate partitions between the cells of the columnar portions of the electric organ. The electric organs of the Gymnotus are four in number, arranged in two pairs, one larger than the other; they form one-third of the entire bulk of the animal, and extend nearly its whole length. Their structure is similar to that just described in the Torpedo; but the prismatic columns of cells are larger, fewer in number, and of greater length, for they are placed lengthwise in the electric organ and body of the Fish. The nerves are derived, it is said, from the spinal cord only, and are upwards of 200 on each side of the body. Some of its nerves proceed from the fifth cranial nerve, but most of them, it is asserted, from the spinal cord.

In the Silurus, there is no such distinct electric organ; but a dense fibrous tissue, having albuminous substance contained in its interstices, surrounds the whole body, and is regarded as the homologue of the more perfect organs of the Gymnotus and Torpedo.

The power of the Torpedo to give shocks is comparatively small, but these excite much pain. The shock of the Silurus, and of the largest Gymnoti, which measure twenty feet in length, is sufficient to kill small animals, and to paralyze men and horses, both as regards sensation and motion. The electric power depends upon the integrity of the nerves connected with the electric organs, as is proved by the results of partial or complete division of those nerves. Small portions of the organ, connected with the body by no other part than a nerve, still retain their electric power. Destruction of the electric lobe in the Torpedo completely destroys the electric power. The discharge of electricity in the Gymnotus may be caused, by touching different points on the same side of the body, or different points on opposite sides of the body; in the Torpedo, it is excited by touching the upper and under surface of the animal. But it is said, that when exactly corresponding points on the two sides, or on the same surface of the body, are touched, no shock occurs, and that not even a current passes through a galvanometer. Contact with one point only induces no shock, and a Gymnotus instinctively endeavors to bring a second point into near relation with anything which touches it. The back of the Torpedo is electrically positive; the ventral surface is negative; the strongest currents are obtained over the electric organ. In the Gymnotus, however, the most powerful shocks are obtained by touching the two extremities of the body, which here present opposite electric states, the head being positive, and the tail negative.

The electric discharge from these Fishes not only produces shock to the living nerves of one individual, or even of a chain of persons touching each other's hands, but it affects the galvanometer, magnetizes needles, accomplishes chemical decompositions, and even produces a spark in a properly devised circuit. (Faraday.) There can be no doubt, therefore, of its perfect identity with the electricity developed by physical means.

The energy of the electric discharge depends on the size and strength of the animal. It is exhausted by too frequent use; sometimes a powerful discharge precedes death. Torpedoes, in which the electric nerves have been divided, appear to live longer than those the electric organs of which are subject to repeated irritation. The electric energy, like that of the vital processes generally, is greater, and less easily exhausted, in young Torpedoes than in older ones, and shocks have been felt even from the fœtal Fish, as it has been extracted from the abdomen of the parent. Just as the embryo of the Snapping Turtle has been seen to snap its jaws whilst still in the egg, so the fœtal Torpedo has been seen to try and bring its surfaces in proper contact with foreign bodies, so as to pass the shock through them. The electric power is first excited, and then destroyed, by strychnia and morphia. A temperature of 32° suspends the power, which is again restored by immersion of the Fish in water at a temperature of from 58° to 68°; at 86°, rapid and strong discharges take place, and the Torpedo soon dies.

The *use* of this remarkable power, beyond that of serving for protection, or for obtaining food, is not evident; indeed allied Species, exposed to the same enemies, and living on the same food, flourish without such organs. Moreover, the Gymnotus kills many more fishes than it eats, and Torpedoes, kept in confinement, have been found to destroy small fishes without eating them. The electric discharge has been supposed to assist indirectly in the digestive process, inasmuch as animal substances subjected to powerful electric currents, undergo ready decomposition; the intestine of the Torpedo is very short, but so also is the digestive canal of the allied Species. It has also been imagined that oxygen may be supplied to the gills, by decomposition of the water near them by these organs; but this is improbable. Lastly, it has been thought that they may render the Fish galvanometric, and thus enable it to recognize changes in the electric condition of the surrounding medium. The chief use, however, must surely be protective. It has been said that certain Molluscs and Insects are able to emit feeble shocks of electricity, but this is doubtful. The Cœlenterata, as the Sea-Anemones and others, irritate and destroy their prey by stinging organs, which act suddenly, but are not really electric.

The great size of the nerves distributed to the electric organs, the special distribution of the extremities of the nerves upon the membranous walls of the cells, the results of division of those nerves, and of destruction of the so-called electric lobe, the excitement of the organs by irritation of the brain, and, lastly, the apparent subjection of the whole apparatus to the will of the animal, show, that in some way the electric phenomena developed in these living galvanic batteries, are largely dependent on the nervous system. According to one view, the electric force may be developed and accumulated in the electric organ, and may be merely discharged under the influence of the nerves.

But it is difficult to understand how this could happen in an organ apparently uninsulated, for its membranous envelope is as good a conductor as moist tissues or water. Another theory supposes that static electric currents, similar to those which are detected in muscular tissue, but of a far more powerful kind, are constantly circulating through these organs; and that the equilibrium of such currents being disturbed by some action of the nervous system, a discharge of the electric force then takes place. In accordance with this view, the organs themselves, with their vascular cell-walls, seem constructed for a special purpose, being unlike any other known animal organ; after repeated discharges, time must be allowed for the restoration of the power of giving shocks; and, lastly, the electric force is precisely proportioned to the general activity of the nutritive functions. Moreover, a difference has been observed in the character of the discharge or shock, between the Torpedo and the Gymnotus, a difference connected with peculiarities in the structure of their electric organs. The shock is more powerful in the Gymnotus, the piles of cells of the organ being extremely long; whereas in the Torpedo the shock is less powerful, and the piles of cells are shorter. It has been supposed, by some, that the so-called nerve-force is directly converted, in these organs, into electric force; and the further inference has been drawn, that the two forces are hereby shown to be identical. The former hypothesis may be correct, but the latter opinion is not so (p. 232). The two forces are so far related, that either most easily excites the other. The ultimate source of the electric power is chemical action, most probably oxidation.

STATICS AND DYNAMICS OF THE HUMAN BODY.

Physiology is not sufficiently positive or perfect, as a science, to have its exact *constants*. But we may here collect certain numerical expressions concerning the specific gravity, height, and weight of the body; the weights of its various organs; the relative quantities of its chief proximate chemical constituents; also, concerning the weight of the daily food, and its proportion to the weight of the body; its proximate constituents, and the relations of these to the proximate constituents of the body; their destination in the economy; and the effects of deprivation of food.

Besides this, we may examine, in a general manner, the *chemical work* performed within the body; and endeavor to estimate, numerically, its *vito-chemical* processes, and their relation, on the one hand, to the food, drink, and air, and, on the other, to the *mechanical* and *calorific* work performed in, and by, the system. The *nutritive*, *electric*, and *nervous* work, may also be here again noticed.

STATICS OF THE HUMAN BODY.

Specific Gravity of the Body.

The specific gravity of the body depends upon that of its various tissues and organs. Essentially, all the materials of the body, with the exception of the fatty substances, are heavier than water, and the mean specific gravity of all the tissues is higher than that of water. But the air retained in the lungs during life, even the residual and reserve air, is just sufficient to counterbalance the higher specific gravity of the body generally, and so enables it to float (p. 183).

The specific gravities of the chief tissues are given in p. 70; that of the principal organs is mentioned in their description. The specific gravity of the entire body, with air in the lungs, is usually stated to be from 1060 to 1070. As bone is the heaviest, and fat the lightest, of the tissues, the specific gravity of the entire body is influenced by the relative proportions of these two tissues; hence it is greater in thin bony persons, but less than the average in children and women, who are generally fatter than men, and also in corpulent persons of either sex. But the practical buoyancy of the body in water, is, of course, chiefly determined by the size of the chest and lungs, the freedom of the latter from congestion or deposits, and their condition of inflation. On the least inspiratory and expiratory movement the body rises or sinks in water. Necessarily, the body is more buoyant in the sea than in fresh water. The effect of clothing, or of any kind of weight, is, of course, adverse to buoyancy.

Height of the Body.

The human body continues to grow, at least up to the age of twenty-five (Quetelet), and, as it would seem, even up to the age of thirty years. (Danson.) The mean height of the male in Belgium, at twenty-five years of age, is 66.1 inches, or 168 centimetres.* (Quetelet.) The mean height of males, at twenty-one years, in Germany, is found to be 68.1 inches, or 173 centimetres. (Zeising.) Measurements of 4800 criminals, in England, give a mean height in the male, from twenty-five to thirty years, of 66.5 inches or nearly 169 centimetres. (Danson.) The extreme divergence of the German measurements, must be exceptional, and due probably to too limited a number of observations. The English stature is nearer to a mean. The height of the full-grown female, at thirty years of age, is 62.2 inches, or 158 centimetres. (Quetelet). The mean difference between the height of the sexes, is about 4 inches.

Weight of the Body.

The estimated average weight of the body in the male, is also rather less, according to Quetelet, than according to other observers. From thirty to forty years of age, it is 140 lbs., or 63.66 kilogrammes.† From twenty-five to thirty years of age, the mean weight of the male, according to Danson, is 143.1 lbs., or 65 kil. Vierordt adopts the result of one observation on a powerful male, aged forty-two, whose weight was about 143.5 lbs., or 65.25 kil. The weight of the female, at thirty, is 121 lbs., or 55 kil., *i. e.*, about 22 lbs. less than that of the male; but the weight increases in women up to the age of fifty, when it is about 123.2 lbs., or 56 kil.

From the preceding numbers, a mean height of 5 feet 6½ inches, and a weight of 144 lbs. avoirdupois, may be assumed, for the average full-grown male. In the calculations made by English writers, on the working power of a man, 150 lbs. is, however, usually taken as his weight.

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* A centimetre = .3937 inch.
† A kilogramme = 2.2 lbs. avoirdupois.

Weights of different Parts and Organs of the Body.

These are taken from Duroy and Krause, the weights given by them having been converted into lbs. and ozs. avoirdupois:

	lbs.	oz.	oz.
The recent skeleton,	21	8	344
Muscles and tendons,	77	8	1240
Skin and subcutaneous fat,	16	5	261
Brain,	3	2½	50.5
Spinal cord,		1¼	1.25
Eyes,		½	.5
Tongue and hyoid bone,		3	3
Œsophagus,		1¾	1.75
Stomach,		7	7
Small intestine,	1	11½	27.5
Large intestine,	1	1	17
Salivary glands,		2½	2.5
Liver,	4	1½	65.5
Pancreas,		3	3
Spleen,		8½	8.5
Thyroid body and remains of thymus,		¾	.75
Blood = $\frac{1}{13}$ weight of body,	11	0	176
Heart,		10¼	10.25
Right and left kidneys,		10¼	10.25
Larynx, trachea, and larger bronchi,		2¾	2.75
Lungs,	2	10¼	42.25
Unweighed parts,	1	4¾	20.75
Total,	143	8	2296

Proportions of the Proximate Constituents of the Body.

All the constituents of the body belong to five chief categories; viz., albuminoid substances, and those immediately derived from them, fats, salts, extractives, and water. The following Table shows the quantities of these substances in a body supposed to weigh 150 lbs.; and also the proportions of each in 1000 parts. (Moleschott):

	Quantities in the body in lbs.	Proportions in 1000 parts.
Albuminoid substances and their derivatives,	30	201
Fatty matters,	4	25
Salts,	14	92
Extractives,	1	6
Total solids,	49	324
Water,	101	676
	150	1000

Daily Quantity of the Food, and its Composition.

It has been stated that a daily consumption of 2 lbs. of bread, with 12 oz. of meat, which contain 11.6 oz. of carbon, and .7 oz. of nitrogen, will support a fully-exercised adult. (Béclard.) According to another estimate, 1 lb. of meat, 1 lb. 3 oz. of bread, $3\frac{1}{2}$ oz. of fat, and about $2\frac{1}{2}$ imperial pints of water, are needed by a healthy actively-employed man. (Dalton.) Vierordt's estimate, as we shall see, assigns 4 oz. of dry albuminoid matter, 3 oz. of fat, $11\frac{1}{2}$ of starchy food, and 1 oz. of salts. An ordinary English laborer is said to consume daily, a diet containing 12 oz. of carbon, and 5 of nitrogen, and a dietary containing only 10.4 oz. of carbon, and .42 of nitrogen, is stated to be insufficient to preserve his health. (Ed. Smith.) Cases, however, are on record, such as that of Louis Cornaro, in which a much lower diet has served to maintain life and health for very long periods. The diet of men engaged to run, walk, or row, and also that of jockeys, has occupied special attention in England; and though entirely the result of empiricism, the rules laid down, correspond generally with the suggestions of science. They usually include an excess of meat diet, a spare allowance of amylaceous and saccharine food, and a more or less strict abstinence from alcoholic beverages, tea, coffee, and tobacco. Very active exercise, sweating, sponging, early rising and retirement to rest, are also enjoined.

The daily food may be classified under four chief categories; viz., the albuminoid substances, the fatty and starchy substances, the saline or mineral substances, and the water. According to Vierordt, a healthy adult is sufficiently nourished, by consuming daily, 4.2 oz. av. of dried albuminoid substances, 3.1 of fatty matter, 11.5 of amylaceous food, and 1.1 of saline substances. Playfair has estimated that the daily diet of an active adult man is about 4.2 oz. of dry albuminoid substances, 1.8 of fats, 18.7 of starch, and .9 of mineral substances. The difference between these diets, the former preponderating in fatty matters, and the latter in starchy substances, is doubtless owing to differences of national habit. To these solid substances, viz., 19.9 oz. in the former, and 25.6 oz. in the latter diet, must be added 93 oz. of water, which, according to Vierordt, includes that taken both in the food and drink, making a total of 112.9 oz. in the first diet, and 118.6 in the second diet. The daily amount of new material taken into the body, will, in the former case, be about $\frac{1}{20}$th, and in the second, about $\frac{1}{19}$th, of the total weight of the body. In the diet indicated by Vierordt, the proportion of non-nitrogenous to nitrogenous food, is as $3\frac{1}{2}$ to 1; whilst in that allowed by Playfair, it is as $4\frac{3}{4}$ to 1. But a compensation exists in the fact, that the fatty matters, in excess in the German diet, are much richer in carbon than starch; for, adopting the so-called starch equivalent for fat, which is as 2.4 to 1, and expressing the fatty matters, in both diets, as if they were starch, the disparity between them is lessened. The starch equivalent in the former diet would then be 19, and in the latter 23, which, as compared with the amount of nitrogenous matter identical in both diets, viz., 4.2 oz., would give a ratio between the non-nitrogenous, or hydro-carbonaceous elements, and the nitrogenous, of about $4\frac{1}{2}$ to 1 in the diet of Vierordt, and of about $5\frac{1}{2}$ to 1 in that of Playfair.

The annexed Table shows these facts more clearly.

DAILY FOOD OF AN ADULT MAN, IN OZS. AVOIRDUPOIS.

	Playfair.	Vierordt.	Proportions in 1000 parts (Vierordt).
Albuminoid substances,	4.2	4.2	37
Fatty matters,	1.8	3.1	28
Salts,	.9	1.1	8
Starch,	18.7	11.5	103
Total solids,	25.6	19.9	176
Water,	90	93	824
	115.6	112.9	1000

Relations between the Constituents of the Body and those of the Daily Food.

Having determined the proportions of the different proximate constituents of the body, in 1000 parts, and the same proportions in regard to the proximate constituents of the food, and knowing that the total weight of the daily food is about $\frac{1}{20}$th of the total weight of the body, it is easy to ascertain approximately, the ratio between the daily quantity of each of those proximate constituents of the food, and the quantity of the same, or similar substances, present in the body. The results are shown in the annexed Table.

	In 1000 parts of the body.	In 1000 parts of food.	In 50 parts of food, *i. e.*, $\frac{1}{20}$ the weight of the body.	Proportion per cent. of constituents of food, to similar constituents in body.
Albuminoids,	201	37	1.85	.9
Fats,	25	28	1.4	5.6
Salts,	92	8	.4	.4
Carbhydrates, viz., starch, sugar, extractives,	6	103	5.15	86
Water,	676	824	41.2	6.1
Totals,	1000	1000	50	

From this comparison, it appears that, in round numbers, the daily supply of albuminoid substances in the food is rather less than 1 for every 100 parts of albuminoid materials in the body; that the supply of fat is $5\frac{1}{2}$ parts for every 100 in the body; that of salts, less than $\frac{1}{2}$ a part; and of water, 6 parts only for every 100. On the other hand, the proportion of the carbhydrates in the food, as compared with the small quantity of substances of similar composition in the body, is as much as 86 per cent. This obviously suggests that the amyloid and saccharine substances are not largely employed for conversion into tissue, but have some other function in the economy, one of which, there is reason to believe, is to supply fuel for the purposes of generating chemical force, to be transformed into animal motion and heat. These, indeed, are the so-called calorific substances, *heat-givers*, or *respiratory* food, as distinguished from the albuminoid substances, *plastic* food, or *flesh-formers*. From the small percentage of these latter bodies, daily supplied to the system, it is evident that not more than $\frac{1}{100}$th part of such substance in the body can, on an average, be replaced by nutritive metamorphoses in one day. Hence, we arrive at the conclusion, that 100 days, at least, are necessary, supposing waste and supply to be equal, for the complete transformation of *all* the albuminoid, and their derived constituents, in the living body. But the actual rate of metamorphosis, is so different in the several albuminoid tissues, as *e. g.* in muscular, as compared with tendinous, tissues, and moreover, so inconstant, that no safe conclusions can be arrived at upon such general data. The fatty matters of the body are possibly changed in much less time.

It is difficult to estimate the ordinary daily waste of the human body. It has been shown, however, that the daily quantity of food necessary to maintain an animal at its normal weight, is more than twice the weight of the daily loss which it undergoes, when deprived of all food. When the weight of the food is only equal to the loss during temporary starvation, the animal continues to lose weight, and the egesta given off by the alimentary canal, the kidneys, the skin, and the lungs, weigh more than the quantity of food taken. This has been attributed to the requirements of the processes of digestion, which demand the formation of copious secretions containing much solid matter; but as most of them are reabsorbed, it is more probably to be explained by the fact that, in a starving animal, the waste is reduced to a minimum, and that the effect of insufficient food is to excite the system to an unaccustomed activity, and to loss by metamorphosis. Nevertheless, during health, with sufficient food, and in a sufficiently long period, there must be an actual balance between the loss and the supply.

Destination of the Food in the Living Economy.

This subject includes two points of investigation—viz., the *intermediate*, and the *ultimate*, *chemical changes* or metamorphoses of the different proximate constituents of the food. The latter point may be first examined.

In order to arrive at the *ultimate* destination of the proximate constituents of the food, after these have compensated for the waste of tissue, or have been consumed in furnishing force for imparting motion and heat, it is necessary to determine the intrinsic composition of those constituents, and that of the various excreted matters. The chemical constitution of the *ingesta* which pass into the body, must be compared with that of the *egesta* which pass from it—two terms of an equation, which, if our means of experiment, and our knowledge, were exact, should be shown precisely to correspond. This comparison has been attempted by Vierordt, as shown in the following Tables, in which the quantities given by him in grammes, have been reduced to ozs. avoirdupois:

A. Ingesta during 24 hours, in ozs.

Food, drink, and air.	Quantities consumed.	H_2O of starch, and water.	C	H	N	O	Salts.
Albumen, ...	4.23		2.29	.28	.66	1	
Fat, ...	3.17		2.47	.36		.34	
Salts, ...	1.13						1.13
Starch, ...	11.63	6.46	5.17				
Water, ...	93	93					
Oxygen of air, . .	26.24					26.24	
Totals, . .	139.4	99.46	9.93	.64	.66	27.58	1.13

B. Egesta during 24 hours, in ozs.

Excretions.	Quantities excreted.	Water.	C	H	N	O	Salts.
Breath; Carbonic acid and Water,	43.4	11.66	8.79		?	22.95	
Perspiration; do. do.	23.62	23.3	.09			.23	
Urine, { Urea, Water, Extractives, }	62.31	59.98	{ .24 .1	.07 .03	} .56	.41	.92
Solid excreta, ...	6.07	4.52	.71	.1	.1	.43	.21
Water formed in the system,	4.			.44		{ .27 3.29	
	139.4	99.46	9.93	.64	.66	27.58	1.13

In Table A, the quantities of the various constituents of the daily food, solid and fluid, are the same as those quoted in p. 898. The daily amount of oxygen introduced into the system, is calculated from the quantity known to be given off, in that period, as carbonic acid from the lungs and skin. The quantities of hydrogen and oxygen which exist in the carbhydrates, in the proportions to form water, are set down as water.

In Table B, the ultimate destination of all the chemical elements of the constituents of the food, is traced. The totals under each head in the two Tables correspond, the decimals having been, in some cases, slightly altered in the reduction of grammes into ounces. The upper row of the figures which refer to the urine, represents the elements of the urea; the lower row, those of the non-nitrogenous urinary constituents. Above two-thirds of the hydrogen of the food are converted in the body into water, partly by uniting with oxygen already in the food, but chiefly by combination with oxygen from the air. The remainder of the oxygen unites with carbon, to form the carbonic acid of the pulmonary and cutaneous exhalations. Of the entire excreta, 32 per cent. pass off by the breath, 17 by the skin, 46.5 by the kidneys, and 4.5 by the alimentary canal. The ultimate products of the chemical metamorphoses of the food within the living body, are regarded essentially as *urea*, *carbonic acid*, *salts*, and *water*. The small residue consists chiefly of nitrogenous and other matters in the fæces, and of epithelial, and epidermoid losses.

The *intermediate* stages of metamorphosis, which occur as the food is assimilated into blood, or solid tissue, and the further exceedingly complex and only imperfectly known changes which these undergo, have been followed, more or less completely, in describing the composition and use of the different kinds of food (p. 481–5), the modes of their assimilation (p. 621), the office of the several constituents of the blood (p. 707), and the sources of the biliary and urinary pulmonary excretions (pp. 760, 777). A summary or general view of these metamorphoses may now be given.

Water appears to undergo no decomposition into oxygen and hydrogen; rather it is increased by additional water set free, or actually produced by the union of oxygen and hydrogen in the body itself. It is probably concerned in processes of hydration and dehydration, thus effecting changes in the more complex elements of the body.

The *saline* substances of the food pass, for the most part, unchanged through the body, and reappear again in the excretions, especially in the urine; but the chlorides must undergo temporary decomposition for the formation of the hydrochloric acid of the gastric juice, the chlorine, however, again meeting with appropriate bases. Additional saline matters appear in the excreta besides those in the food, chiefly alkaline sulphates, formed by the oxidation of the sulphur in the albuminoid compounds of the body, the magnesian phosphates, resulting from the oxidation of the phosphuretted fats of the blood corpuscles and the brain. The ammonia in the breath, in the perspiration, and in the urine, and also the urea, uric acid, and hippuric acid, are saline substances, the products of decomposition of one or more nitrogenous matters in the body.

The carbhydrates, starch, and sugar, are changed, the first into sugar, and both, probably after transitional mutations, into lactic, oxalic, or other acids. Their elements are ultimately traceable, the carbon, in the carbonic acid of the breath and perspiration, and the hydrogen and oxygen, in water. Sometimes starch or sugar may give rise, apparently by an upward metamorphosis, to biliary or other fatty acids, and thus to fat, which may then be deposited in the tissues as fat, or they may protect and thus spare the fat already in the body. Sugar and starch given with meat or albuminoid food, produce obesity; they are even more fattening than fat itself, as they are more easily oxidized, and act more effectually as protectors to the other constituents of the body. Ultimately, their elements are, in any case, subjected to the same oxidizing processes, yielding *carbonic acid and water.* Their upward transformation is probably exceptional, because they are more easily oxidizable than fat.

The *fatty* matters, or hydro-carbons, are usually decomposed into their fatty acids and glycerin, before they enter the chyle, and are probably recomposed there, or in the blood; possibly, also, they are again decomposed, under the influence of the alkaline constituents of the blood, on the eve of being oxidized. This oxidation may be direct or immediate, into carbonic acid and water; but the fat may be first employed, perhaps in the formation of the choleic acid of the bile, or of the volatile fatty acids of the milk, butyric, capric, and caproic; or it may be still further resolved into propionic, formic, or acetic acids, and so pass to the ultimate condition of *carbonic acid and water.* The hydrogen of fat, being in excess of its oxygen, and not in the proportions to form water, as in the carbhydrates, this element and the carbon, which also exists in excess, demand, for their reduction, a much larger relative supply of oxygen from the air. Hence, in regard to vito-chemical calculations, the fats may be represented by a *starch equivalent*, 1 part of fat being equal to 2.4 parts of starch. A minute portion of fat may remain almost unoxidized, in the form of cholesterin. Fat, like the carbhydrates, also saves the metamorphosis of the albuminoid tissues and food; for if an animal be fed on insufficient animal diet, to which some fat is added, there is less waste, and a smaller consumption, of nitrogenous matter, than if it be fed on a scanty meat diet without fat. A normal proportion of fat in the food also saves the consumption of meat; for the weight of an animal is then maintained with one-third or one-fourth less meat, than when it is fed on meat alone. An excess of fat in the diet, however, has, as its chief result, an increase of weight, by accumulation of adipose tissue. The most successful plan of fattening animals, is not to withdraw the albuminoid foods, but to allow these to remain the same in quantity, and to increase the hydrocarbons and carbhydrates. The researches of Lawes and Gilbert show that in the fattening of animals, much more fat is produced than there is fat in the food, only $\frac{1}{9}$th, or $\frac{1}{3}$d being contained in the food, and therefore, from $\frac{2}{3}$ds to $\frac{8}{9}$ths being produced from other sources, largely from the carbhydrates, but also from any excess of nitrogenous food, after the albuminoid tissues are supplied. This is especially the case, if the non-nitrogenous food be defective, or if an animal be fed on flesh only. (Voit.)

Alcohol, which may be considered as one type of hydrocarbonaceous food, has been said, by some, to escape wholly unchanged, by the breath and the excretions; but it is generally believed to be, at least, partly oxidized, either with or without previous conversion into aldehyde, acetic acid, or some other intermediate substance or substances. It is not supposed to contribute directly to the formation of tissue, not even of fat. It is not essential as an article of diet; it may even be detrimental, by its chemical action on albuminoid substances, hardening and precipitating them, or by its physiological action, stimulating or even poisoning the nervous system, or producing slow and insidious changes in the blood, the tissues, and the secreting and excreting organs, which render the system unable to resist injury or disease; it may even lay the foundation for irremediable organic changes in the brain, heart, bloodvessels, liver, and kidneys. In smaller and more moderate quantities, alcohol, however, is probably oxidized in the blood, and so serves for the development of motion and heat. It restores a feeble pulse, quickens the vascular action, and so raises, for a time, the vital activity of all the functions, vegetative as well as animal. Much difference of opinion exists as to the claim of alcohol to be regarded as an aliment, of course of the non-nitrogenous class. Alcohol certainly enters the circulation; but its effect on the blood is not understood, though it has been supposed to render that fluid thicker, and the blood plasma less fit for penetrating the tissues. Persons have been known to live long periods on alcoholic beverages, but not on pure alcohol, unless this was accompanied by small quantities of bread or other food. So also persons who drink much beer become fat, but spirit-drinkers do not. It has been supposed to be possibly nutrient to the nervous system, but this is not established, and its plastic properties may be doubted. Whether it may act by saving tissue, through its own oxidation, or whether it may serve as respiratory or calorific food, depends on its ability to undergo oxidation in the system. According to Lallemand, Perrin, and Duroy, it leaves the body entirely, and unchanged; this view is also, in some measure, supported by Dr. E. Smith. By these authors, alcohol has been found *unchanged* in the blood, in the various organs, especially in the liver and the cerebro-spinal nervous centres, and also in the breath, the perspiration, and the urine, moreover, they have not found aldehyde, nor acetic or oxalic acids, into which alcohol has been said to be changed, in the body. It has also been shown that aldehyde, if administered, is itself unstable in the system, and appears as acetic acid. But the quantities of alcohol found in the excretions do not appear to have been accurately compared, by those observers, with the quantity actually taken into the stomach. Baudot and Thudichum have shown that when this is done, the quantities eliminated are proportionally small. Even in the results obtained by Lallemand, Perrin, and Duroy, only $\frac{1}{4}$th of the alcohol taken is thus accounted for. (Gingeot.) In these cases, and also in those in which enormous quantities have been given in disease, more or less alcohol must therefore be appropriated, or assimilated, by the tissues, be retained in them, or be oxidized. The administration of alcohol does not increase, but diminish, the temperature (Perrin, Dumeril, Demarquay, Ringer, and Rickards), and also the quantity of carbonic acid gas evolved. (Lehmann, Vierordt, Hammond, Böcker, Lallemand, and Dr. E. Smith.) The quantity of urea excreted is likewise diminished. Duchek and Mialhe supposed that this was owing to the formation of aldehyde, or some other compound not so perfectly oxidized as carbonic acid; but this is hypothetical. The effect seems rather to be due to its lowering, in some manner, all those organic processes which lead to the formation of carbonic acid by the disintegration of blood and tissue (Moleschott, Carpenter); in this way, alcohol may retard waste, and conserve power. It may also favor the formation of new tissue, and save the combustion of fatty matter. (Hammond.)

Albuminoid bodies, the most complex substances in the animal economy, undergo, as might be supposed, the most complicated intermediate changes, before they are ultimately resolved into their simplest excretory products. Albumen itself, constituting the pabulum of the tissues, does not undergo any upward chemical metamorphosis; all its changes are necessarily retrograde. Slight modifications, perhaps of hydration, convert it into albuminose, pepsin, salivin, and pancreatin. Equally slight oxygenation probably changes it into globulin, fibrin, syntonin, and casein; this, together with a loss or total deprivation of sulphur, is concerned in the production from it of keratin, chondrin, and gelatin; the disappearance of the sulphur must be an essential step in the nutrition of the gelatin-yielding tissues. The substitution of iron, perhaps, for hydrogen or carbon, with a loss of oxygen, is possibly the mode of derivation of the cruorin, or blood pigment, from albuminoid matter; whilst the other pigments, pulmonary, cutaneous, biliary, and urinary, especially abound in carbon, and may be formed by processes of dehydration. The nitrogenous acid of the nervous substance, cerebric acid, is probably derived, directly or indirectly, from some breaking up of albumen, but this peculiar acid, which contains phosphorus, exists in Indian corn and other food; the glycocoll and taurin of the glycocholic and taurocholic acids of the bile, also, perhaps, proceed from the dissolution of albuminoid substances; and it is more than probable that glycogen, or animal starch, and taurin, are formed in the liver, likewise by the splitting up of albumen.

In this case, the glycogen contains the carbon, with hydrogen and oxygen in the proportions of water, whilst the choleic acid, with the glycocoll and taurin, contain, besides those elements, the nitrogen and sulphur. The formation of gelatinoid substances from albumen, which must happen in nutrition, liberates sulphur, which may either be oxidated, or find its escape in the taurin of the bile. Albumen may even be a source of common fat; for the biliary acids might easily give rise to oleic and other fatty acids. During the changes due to the development of the eggs of the limnæus or water snail, the percentage of albumen in the ova, after drying, is said to be diminished from 95.2 to 91.8, whilst that of the fatty matter is increased from .6 to 2.2; the percentage of salts is increased from 4 to 6. (Burdach.) It is further alleged that albumen is resolvable into glycogen and urea, a change which is supposed to be the origin of the sugar formed in the system in diabetes, at least when no starch or sugar is taken in the food. (Haughton.) In this case, the albuminoid matter is supposed only to have been assimilated into the blood, not to have entered into the formation of tissue.

If albumen be broken up in the liver, then its non-nitrogenous products are resolved into *carbonic acid* and *water;* the sulphur appears in the alkaline sulphates, except when it passes off as dyslysin in the solid excreta, whilst the nitrogenous bodies ultimately reach the chemical condition of *urea*. But the more obvious metamorphosis of the albuminoid bodies, is that which consists of a series of retrograde chemical changes into more oxidized nitrogenous bodies, such as creatin, creatinin, leucin, tyrosin, inosinic acid, sarcin, xanthin, hippuric acid, and uric acid, by which path they ultimately reach the condition of *urea*, a substance identical with cyanate of ammonia, and which has also been regarded as a carbamide or a carbide of amidogen, which contains carbon, hydrogen, nitrogen, and oxygen. The ammonia found amongst the saline constituents is probably always derived from a further breaking up of urea.

Albumen may be artificially decomposed, by acids or alkalies, or by spontaneous changes, into leucin, tyrosin, and glycocoll, all which nitrogenous compounds are found in the body, especially in venous blood, and in the liver and spleen; whilst creatin, creatinin, and inosinic acid, are found in actively exercised muscles, and in the blood. Creatinin is, of all these substances, the nearest to urea, and is readily converted into it, by assumption of the elements of water. Urea itself has been found in the muscles of certain fishes. *Gelatin* and the gelatinoid substances, behave in their downward metamorphoses like albuminoid bodies, yielding especially urea, but no sulphur compounds. It is doubtful whether they ever undergo an upward metamorphosis into albumen; but they may spare the waste of this, and may save, and even nourish, the gelatin-yielding tissues. Large quantities alone are useful for this purpose; when much gelatin is taken in the food, the urea is increased in the urine, the specific gravity of which has been known to rise to 1034.

One important inference from our present knowledge concerning the chemistry of the food in the body, is this: that all food may be either oxidized after being merely absorbed or assimilated into the blood, as well as after its constituents have been converted into tissue. This is sufficiently obvious as regards carbonaceous and hydrogenous food, or the respiratory food; but it is equally true of the plastic albuminoid and gelatinoid substances. The excretion of urea is not so much increased by muscular exertion as was once supposed, but it is largely augmented by an excess of nitrogen in the food. (E. Smith, Voit, Lehmann, Fick and Wiscilenus, and others.) The excess of any substance in the food, beyond that which is necessary for the tissue and for respiration, is known as the *luxus consumption*, or *diet of luxury*; it reappears in an increased excretion of urea, carbonic acid, and water.

Interesting deductions may be drawn from comparing the destination of the food in the Herbivorous and Carnivorous animals. In the Herbivora, a very large proportion of the carbon, hydrogen, and nitrogen of the food passes off undigested from the alimentary canal; whilst in the Carnivora, nearly all the food constituents are absorbed into the chyle or blood. Of the carbon which thus enters the blood, the ratio of that given off by the lungs and skin, to that excreted by the kidneys, is, in the Herbivora, about as 30 to 1, whilst in the Carnivora, the proportion is only as 10 to 1. Of the hydrogen absorbed, a greater relative proportion is also found in the cutaneous and pulmonary excretions, in the Herbivora, viz., 25 to 1, as compared with the urine; but in the Carnivora, the proportions in the urine, as compared with the breath, are reversed, being as 3.25 to 1. The nitrogen, in the Carnivora, passes almost exclusively into the urine, the proportion to that in the skin and lungs being as 99 to 1; in the Herbivora, the ratio is only as 1.5 to 1. The excreta in a Carnivorous animal, represent also the excreta of an animal fed on a pure flesh diet; but those of an Herbivorous animal exhibit the results of an excess in the proportion of the carbhydrates, viz., an increased activity of the pulmonary and cutaneous exhalations.

It must further be observed that the quantities of the albuminoid substances, or their derivatives, removed in a solid form from the body, in the mucous and unused secretions of the digestive canal, in the epithelium, from other mucous membranes, and with the epidermis, nails, and hair, are very small, and escape all active metamorphosis.

Finally, the sum of all the chemical changes in the body, is *oxidation*. The carbon of all the carbhydrates and hydrocarbons, appears as *carbonic acid*, and their hydrogen and oxygen, as *water*. A portion of the carbon, hydrogen, and oxygen, of the decomposed albuminoid bodies, also appears in the excreta, as *carbonic acid* and *water;* but a considerable portion of these elements with the nitrogen, is discharged in the form of *urea*. The sulphur and phosphorus produce their respective oxygen acids. For these changes, a larger amount of oxygen, beyond that contained in the body, is needed; and this is supplied by the atmosphere in respiration. It has been computed, that 100 parts of dried meat require 167 parts, by weight, of oxygen, for their disintegration in the body. The results appear as 182 parts of carbonic acid, 52 of water, and 31 of urinary products; whilst only 2 parts escape unchanged from the alimentary canal. No pure carbon, hydrogen, or nitrogen, is evolved from the body, but only chemical combinations of these elements, with oxygen, or with each other. Ammonia is one of these. The minute quantities of carburetted and sulphuretted hydrogen, sometimes disengaged, are probably direct products of the decomposition of the food, and not the results of vito-chemical processes. Of the carbon, 8.8 oz. are evolved as carbonic acid from the lungs, nearly 0.1 oz. from the skin; 0.34 oz. escape by the urine, and 0.71 oz. by the solid excreta. All the nitrogen appears in the two latter excretions, 0.56 oz. in the former, and 0.1 oz. in the latter.

The so-called respiratory, calorific, or heat-giving, elements of the food, chiefly enter the blood, and there undergo oxidation; whilst the plastic, histogenetic, or tissue-forming elements, unless taken in excess, first build up the blood corpuscles and the solid tissues, and then undergo oxidation; but these latter in reality contain fat and often sugar, which may be immediately oxidized in the blood; and so even an albuminoid diet may, in that case, act as respiratory food. This must be the case in starving men and animals, in animals fed on a pure flesh diet freed from fat, and, to a certain extent, in all Carnivora. On the other hand, the carbhydrates are probable sources of fat; and fatty matter is essential to plastic or histogenetic processes. The distinction of the two classes of food is therefore, as previously stated, inexact; even the respiratory food is more or less assimilated, as it enters the chyle and the blood, and both the blood and the chyle are fluid parts of a tissue. Hence even respiratory food is plastic, as regards those fluids.

Effects of Deprivation of Food.

When an animal is entirely deprived of food, or when the quantity supplied is insufficient to compensate for the waste of the tissues, the weight of its body gradually diminishes, and it ultimately dies of *inanition* or *starvation.*

The phenomena attending this condition, have been best studied by Chossat.

The surface of the animal's body looks paler and withered, and the skin seems wrinkled, owing to the disappearance of adipose tissue. The secretions become more scanty and concentrated; hence the mouth is parched, and the digestive fluids wanting; but the gall-bladder becomes distended with thick tenacious bile. From the first, the urine is scanty and strongly acid. The fæces are much reduced in quantity, are composed almost entirely of greenish biliary matter, and, shortly before death, contain an excess both of water and salts.

Nutrition is interrupted or arrested. A warm-blooded animal becomes, after a time, restless and excited, and continues so till the last day of life; a sudden fall in its temperature then occurs, and it passes into a state of almost complete insensibility. Birds, in this condition, no longer attempt to fly; they sometimes gaze at surrounding objects, sometimes seem to be asleep. The pulse and the respiration become gradually slower, and the limbs cold. The general debility increases, until at length, being unable to stand, the animal falls over on one side, and does not again move. Diarrhœa always comes on during the last twenty-four or forty-eight hours of life, and is attended with a peculiar fetid odor of the body, a sign that decomposition is commencing. The condition of stupor gradually becomes more profound, dilatation of the pupil ensues, and the animal dies, death being sometimes ushered in by violent contractions of the muscles of the back, so that the body is drawn backwards, a condition known as opisthotonos.

All the organs of the body suffer loss both in volume and weight, though in very different degrees. Death usually occurs when the animal has lost about $\frac{4}{10}$ths of its weight. In many cases, however, the loss of weight is equal to more than $\frac{1}{2}$, and in others to only $\frac{1}{5}$th of that of the body. This appears to be almost entirely dependent on the quantity of fatty tissue contained in the body, before food is withheld, the loss of weight being greater the larger the amount of fat previously in the system.

In animals which had lost $\frac{4}{10}$ths of their weight, it was found that $\frac{9}{10}$ths of the fat had disappeared, $\frac{7}{10}$ths of the spleen, $\frac{5}{10}$ths of the liver and pancreas, $\frac{4}{10}$ths of the heart, muscles, and alimentary canal—the latter at the same time having undergone considerable shortening—$\frac{3}{10}$ths of the kidneys, $\frac{2}{10}$ths of the respiratory organs, $\frac{1}{6}$th of the bones, $\frac{1}{10}$th of the eyes, and only $\frac{1}{50}$th of the nervous substance. Of the adipose tissue, the fat-cells remain, the contents alone being reabsorbed. The diminution in the quantity of the blood is very great, about $\frac{3}{4}$ths of it disappearing. Young and thin animals suffer much less loss of weight, but they die sooner.

The duration of life appears to be but little affected, whether the animal be allowed to drink, or whether it be totally deprived of water. It has, however, been shown that, if a dog be kept without water, the tissues and organs lose weight, almost in the same proportion as if it had been deprived of solid food, with one exception, for there is little diminution in the adipose tissue. Every tissue becomes drier; but the glandular organs and the brain do not suffer so much as the other parts. There can be no doubt that the drinking of water in starvation prolongs animal life. The smaller Mammalia, and Birds, if they are at the same time deprived of drink, usually die in nine days. Cold-blooded animals live a long time without food; frogs have been known to survive nine months.

As shown by experiments on Birds, the effect of starvation is to diminish the average temperature for the first few days slightly, but as death approaches, very rapidly, the fall being, in the last twenty-four hours, about 25°. The greatest waste of tissue occurs in the fat, whilst the nervous system scarcely experiences any loss; so that the lowering of the temperature, and the fatal result, seem to be due to the loss of oxidizable material, and not to a destructive waste of the nervous energy. The fatty nervous substance may support itself at the expense of the adipose tissue; and this may, in part, account for the great waste of the latter. The effects of exhaustion in long-continued fevers may be similarly explained. The use of fat, as a restorative in the case of starving animals, seems to be, that it interposes an easily oxidizable substance, and so diverts the process of oxidation from the albuminoid tissues; and, in ordinary cases, it preserves the fat already stored up in the body.

In the human subject, *death from starvation* is, though rarely, but too frequently observed. At first, there is acute violent pain over the region of the stomach, which is relieved by pressure. In the course of twenty-four or forty-eight hours, this passes off, and is followed by a sensation of weakness and sinking, which is principally felt over the same part. The mouth becomes dry and parched, the breath is hot, the eyes are wild, staring, and glistening, and there is sometimes a distressing feeling of cold over the whole body. One of the most characteristic symptoms of starvation is the intense *thirst* which now supervenes. The entire body becomes reduced to a skeleton, the prominences of the bones are visible; the face is pale and corpse-like; there is sinking of the eyes and cheeks. A state of extreme debility ensues, so that the individual, in attempting to walk, totters like a drunken man. He is unable to make any effort, and sometimes has been observed to whine and burst into tears. The voice gradually becomes feebler. The weakness increases in intensity, and delirium supervenes. A peculiar fetid odor emanates from the body, the surface of which becomes covered with a brownish offensive excretion. Occasionally, the mucous membranes of the different openings of the body become red and inflamed. The psychical functions are variously affected; sometimes imbecility, at others idiocy, is induced. During the famine in Ireland in 1847, mania, which, according to Rostan, forms a prominent symptom in starvation, was never observed. (Donovan.) A fit of maniacal delirium, or an attack of violent convulsions, frequently, and indeed, commonly, precedes death.

The bodies of persons who have died from starvation present signs of great emaciation, with dryness of the skin, all the fat of the adipose tissue, and so much fluid, having been absorbed. The stomach and intestines are empty, and, like the other large viscera, contracted and reduced in size; their mucous membrane is occasionally found ulcerated. The coats of the small intestine become very thin and almost transparent, a condition considered, by some, as quite characteristic of death from starvation. All the organs, except the brain, are almost destitute of blood. The large vessels connected with the heart and lungs, are collapsed and empty. The gall-bladder is distended with bile, and the neighboring parts are much colored with this fluid, from post-mortem transudation. In some cases, the eyes are open, and exhibit an intense red color, as if they had been highly inflamed, resembling what is sometimes seen in persons who have died from exposure to cold. Decomposition of the whole body quickly takes place.

The time that a Man can live without food has been variously estimated. It is generally supposed that a healthy person, deprived of both solid and liquid food, would die in from seven to ten days. Cases, however, are on record of men who have lived more than three weeks, without touching solid food.

DYNAMICS OF THE HUMAN BODY.

The chemical processes continually occurring in the nutrition and waste of the living animal body, throw light upon many other phenomena which take place in it. Besides these vito-chemical processes, it exhibits various *dynamic* acts, viz., *purely dynamic*, as in the performance of certain internal and external mechanical work, by nervo-muscular action; *thermic*, as in the evolution of animal heat; *electric*, as exemplified in the currents of electricity which constantly play through all living nervous and muscular substance, and in the more powerful discharges of the electric fishes; and lastly, *photic*, illustrated by the evolution of light in the lower animals. The living animal body is, according to this view, a machine, in and by which certain *physical work* is performed.

In the *Inorganic* world, chemical, dynamic, thermic, electric, and photic phenomena are also continually occurring. They are always manifested in connection with certain changes in the condition of a material substratum, or *matter*, and modern physicists have arrived at the conclusion, that, however different these phenomena may be from each other in their outward manifestation, they may be referred, not to a different force in each case, but to correlated forces, or to *one force* or *energy*, capable of acting in many convertible modes. Each mode of manifestation of force has been experimentally shown to be capable of giving rise to the others, or rather of changing into them; for it disappears in so doing, and *equivalent quantities* of those other modes of action are then called into play. Thus, for example, arrested mechanical motion, or friction, produces a proportionate quantity of heat; whilst heat, in the expansion of water into steam, gives rise to motion. Chemical action, in the explosion of gunpowder, produces motion, heat, and light, and doubtless also electrical phenomena, whilst the moving cannon-ball develops heat as it strikes the target. Electricity also will give rise to chemical action, motion, heat, and light, and so on. Heat and all these other actions are modes of motion, either of the masses or of the molecules of matter. In the various conversions of one into the other, there is neither loss nor production, but merely a transmutation of force.

In the *Organic* world, similar manifestations of force occur: chemical, dynamic, thermic, electric, and photic. The *material substratum* concerned, consists of carbon, hydrogen, nitrogen, sulphur, phosphorus, oxygen, and so forth, all being elements which exist in the inorganic world. The phenomena are invariably produced, only in connection with certain changes in the condition of these elements and their compounds. Hence, it seems probable, first, that these organic manifestations of force are likewise correlated within themselves; and, further, that they are also correlated with the corresponding manifestations of force displayed in the inorganic world; that they are the same both in degree and kind; and that they are both derived from a common cosmical energy, the organic modes being, for a time, operative in a special sphere of action, but returnable again to the inorganic store.

By including, in one view, the Vegetable and Animal Kingdoms of the Organic world, the conversion of inorganic materials into organized matter, and its restoration back to the inorganic world, may be readily traced. The carbonic acid, the ammonia represented in the urea, and the water, which, with certain salts, are the ultimate products of the vito-chemical processes of animal life, are the very substances needed for the nutrition of plants. They are themselves actually unorganized, or inorganic; they are assimilated and *deoxidized* by growing plants, under the influence of solar light and the formative agencies of the vegetable cells, and, besides building up those cells, they are combined into all the higher chemical products necessary for the food of animals, whether amyloid, oleoid, or albuminoid. The Herbivorous animals, supported by these products, transfer them to the Omnivorous and Carnivorous animals, including Man himself. By animals, as we have seen, these various products, *oxidized* by the air, once more revert to the same simple chemical compounds destitute of organization. Now, the elementary substances, which enter into the ascending or *pro*gressive metamorphoses in plants, pass out, after their *retro*gressive metamorphoses in animals, with all their properties and qualities unchanged. Engaged in the organic vortex, vegetable and animal, they still retain their nature. However frequently subjected to this temporary diversion from the inorganic state, they are unchanged. It is difficult to suppose that in their condition as parts of organized bodies, vegetable or animal, they manifest mere *similitudes* of their inorganic forces, which they afterwards lay aside; but it is easy to comprehend, that they may carry with them, into their new position, *all* their properties and energies, and exercise them in the manifestation of those phenomena, which are identical in both Departments of Nature.

The methods and reasoning employed in physical research, in the examination of the various external natural phenomena, may be applied to the study of the corresponding phenomena in physiological science. As physico-chemical action, in the inorganic world, is correlated with mechanical work, heat, electricity, and light, so, in the organic world, vito-chemical changes may equally be associated with nervo-muscular or dynamic, thermic, electric, and photic phenomena, and even with the actions usually referred to the so-called nervous force. Thus, a chemical change of blood or tissue, or of both, is essential to muscular and nervous action, to the development of animal heat, to the electrical phenomena of living bodies, and to the evolution of light in animals. So, too, certain mechanical work, performed exclusively within the animal body, must, when completed, pass into heat, as the result of arrest, concussion, or friction. Heat, again, is necessary for the solvent processes accompanying the digestion and absorption of the food; and it exercises a well-known influence upon, and often determines, the quantity of the chemical change and dynamic work performed in the body.

In the Inorganic world considered exclusively, gravitation and solar heat are the chief modes in which force is manifested. The evaporation of water from the surface of the earth, its conversion into clouds, its descent in the form of fogs, rain, snow, or hail, the formation of glaciers, mountain-streams, and rivers; and the production of ascending, descending, and horizontal currents in the atmosphere, are the evidences of these forms of energy. Oxidation and other chemical changes, though not absent, are comparatively inactive in the present condition of the inorganic world.

In the Organic world, however, in plants and animals, chemical change constitutes the most essential modes or forms of force, and the source of the other forms of force manifested by them. Under the influence of certain of the solar rays, differing from the simply heating rays, viz., the luminous and the actinic rays, the deoxidation and fixation of certain elements take place in plants; and in these elements so fixed and combined, a force, derived from the solar rays, is then stored up. In animals, again, oxidation is the essential phenomenon, an opposite chemical change occurs, the force stored up in the animal blood or tissues, which is but a transfer of that of the vegetable constituents of the food, is, together with the force proper to the oxygen of the air, then liberated, and, by the special organic apparatus of the animal body, is changed, as required, into other modes of action, muscular, nervous, thermic, digestive, or excretory, necessary for the maintenance of animal existence. In supplementing the mechanical forces of nature dependent on gravitation or solar heat, such as wind- and water-power, Man has had recourse to chemical change, as a source for the production of heat and mechanical force. The carbon and hydrogen of coal are made to unite with oxygen; from this combination, heat is evolved; by this, water is converted into steam; and, by the expansive force of the latter, the requisite motion is obtained. An obvious comparison is here suggested between a machine and the body, between the force obtained by the combustion of dead matter and the oxidation of the living tissues; and, lastly, between the working of a steam engine and the muscular movements.

In general physics, results, to be of scientific value, must be expressed numerically. The quantity of fuel and oxygen undergoing change in combustion, is accurately determined by weight or volume; the relative amount of heat evolved, is ascertained and recorded; and if the heat be applied, as by expansion for mechanical purposes, the value of the work it performs is exactly measured. By such means, the amount of each kind of force manifested, is expressed in numbers, so that their mutual equivalents, when they are transformed, one into the other, can be determined. The introduction of this method into the domain of physiology, necessitates the determination of the quantity of matter undergoing change by oxidation, and of the work performed by it, in the living body. The results, however incomplete, are full of interest and promise.

In comparing the animal body with a machine having its source of power in combustion or chemical changes, it is usual to make this distinction: in the latter, the force is entirely derived from the combustion of substances introduced into the machine, and acts upon parts of the machine, themselves passive in the work; whereas in the former, the parts of the machine not only perform the work, but, to a certain extent, their very matter undergoes the changes by which the force is produced. In the steam engine, the heat and the mechanical work are produced by the direct transformation of fuel distinct from the machine itself; in the animal frame, the warmth and motor force are evolved from the direct transformation of the fluids and solids of the living apparatus. As will be hereafter seen, the quantity of work accomplished, in proportion to the amount of chemical change which takes place, is far greater in the animal body than in the most economical steam engine.

But, although the solids or fluids of the animal machine undergo chemical metamorphoses, as the indispensable condition of its action, the waste occasioned by those changes is, necessarily, ultimately supplied from the food. If food be taken in excess, as in the luxus consumption, it undergoes oxidation in the blood, without passing into tissue; if the quantity be normal, it enters both the blood and the tissues, and then becomes oxidized; lastly, if the food be withheld, the blood and the tissues undergo oxidation, they having been themselves derived from previously assimilated food. The *food* is, in the last resort, the source and measure of the *power* engendered, as a consequence of oxidation in the body. Accordingly, exact numerical estimates of the work accomplished in the human body, must refer both to the amount of combustible or oxidizable material in the *food*, and to that of the products of its oxidation found in the *excretions*.

The two most obvious forms of work performed in the living human body, are the *proper dynamic* or *mechanical* work, and the *calorific* work. Besides these, however, there are the *nutritive* work, and the *mental* work. The *mechanical* work is nervo-muscular, and is associated with *electric* work. Some of it is *internal*, such as that of the respiratory muscular apparatus, especially of the diaphragm and intercostal muscles, of the organs of circulation, the heart and arteries, and that of the pharynx, œsophagus, stomach, intestines, and other internal muscular organs. Other internal mechanical work is that performed by the muscles which maintain the position of the body, by the muscles of mastication, and by those of the organs of speech and sense, and also the tonic contraction of the whole muscular system. A very large part of the mechanical work is, however, ordinarily *external*, such as is manifested in the movements of *locomotion* and *labor*. The proportion of the internal to the external work, in a laboring man, is as

2 to 1. The *calorific* work relates to the formation of heat; this is generated, as we shall see, either in part, directly through the oxidation of respiratory food, and, in part, indirectly from the ultimate transformation of the mechanical work of the body into heat; or, according to some, it is entirely derived from the latter source. The *nutritive* work is the digestive, absorptive, assimilative, and secretive work, liquefacient or solidifacient, often dialytic, attractive, or repellent. The *mental* work is that which is involved in the operations of the brain, acting as the bodily organ of sensation, emotion, and thought. The volitional work of the brain, and the non-volitional work of the spinal cord and ganglia, in controlling the voluntary and involuntary muscles, cannot be separated from the external and internal mechanical work performed by those muscles. Besides the *electric* work in Man and in animals generally, special electric work is performed by many animals, and *photic* phenomena are manifested by a few.

In considering the relations between these forms of work in the human body, and the source of the power in the oxidation of the food, the following data, belonging to physical science, are usually employed, the calculations being expressed in the French metrical system, which so readily adapts itself to such uses.

Measure of Heat, or Heat-Unit.

The thermometer merely shows the *relative* temperature of solid, fluid, or gaseous substances. The *actual quantities* of heat necessary to produce changes of temperature, are determined by the apparatus known as a *calorimeter;* and the quantity needed to impart to a definite portion of water a definite warmth is taken as a quantitative standard. Thus a quantity of heat which will raise the temperature of 1 gramme (1 cubic centimetre, or 15.543235 grains) of water, 1° Centigrade (1.8° Fahrenheit), is named a *heat-unit* or *calorie.* Ten such heat-units will raise the temperature of 10 grammes of water also by 1° C.; but, acting on smaller quantities of water, they will raise their temperatures proportionally, as, for example, 5 grammes by 2° C., and 10 grammes by 1° C., and so on, of 100's or of 1000's of heat-units.

Mechanical Coefficient, and Mechanical Equivalent of Heat.

Heat may produce work which is internal and direct, as in the liquefaction of solids, *e. g.*, in the melting of metals, and the turning of ice into water, or in the conversion of fluids into vapor, as of water into steam, or in the mere expansion of fluids or gases, as of mercury or air; but heat may, also, act externally and indirectly, as occurs in the employment of the expansive force of steam in machines or engines of various kinds. The quantity of work performable by heat is very remarkable. Thus, starting from the heat-unit previously determined, it has been shown by Mayer, Joule, Clausius, and others, that such a heat-unit, viz., the quantity of heat which will raise the temperature of 1 gramme of water by 1° Centigrade, if utilized by being converted into mechanical work, is equal to the lifting of the same weight of water, viz., 1 gramme, to a height variously estimated at, from 421 to 433 metres, 424 metres being the number usually adopted. Conversely, the same force will lift 424 grammes, 1 metre high; or twice that number, viz., 848 grammes, half a metre; or half that number of grammes, viz., 212, to a height of 2 metres, or 106 grammes, 4 metres, and so on for other quantities, larger or smaller. The mechanical *coefficient* of heat is therefore 424, and the mechanical *equivalent* of 1 heat-unit is expressed as 424 *metre-grammes.* For larger weights, *metre-kilogrammes* are used; and it is here that the decimal notation of the metrical system is so useful. Thus 1 kilogramme of water (1000 grammes) requires 1000 heat-units to raise its temperature 1° Centigrade; and these 1000 heat-units will lift the same weight of water, viz., 1 kilogramme, 424 metres high; or, conversely, 424 kilogrammes, 1 metre high; 212 kilogrammes, 2 metres; or 106 kilogrammes, 4 metres high, and so on. The mechanical equivalent of 1000 heat-units is expressed, therefore, as 424 metre-*kilo*grammes (met. kils.).

In English works the scale of temperature employed is that of Fahrenheit, of which 1.8° are equal to 1° Cent.; the weight is the lb. av., of which 2.2 are equal to 1 kilogramme, and the measure of height is 1 foot, of which 3.28 are equal to 1 metre. The mechanical equivalent of a given quantity of heat is expressed in *foot-pounds*. Thus the heat which will raise the temperature of 1 lb. of water, 1° Fahr., will lift that weight, viz., 1 lb., to a height of 772 feet, or 772 lbs. to a height of 1 foot, and so on; hence the mechanical coefficient of heat in this system is 772, and its mechanical equivalent is expressed as 772 foot-pounds (ft. lbs.). To reduce the English ft. lb. into the French met. kils., divide the former by 7.216, which is the number obtained by multiplying the number of pounds in a kilogramme by the number of feet in a metre, viz., 2.2 × 3.28. On the other hand met. kils. multiplied by 7.216, are changed into ft. lbs.

Not only is heat convertible into mechanical work, but mechanical work may be reconverted into heat, and the same equivalents, as before, express the ratio between them. Thus a mechanical force equal to lifting 1 kilogramme of water 424 metres high, will, when employed in friction, blows, or otherwise, develop a temperature equal to 1000 heat-units, or will raise the temperature of 1000 grammes, *i. e.*, of 1 kilogramme of water, 1° Cent. In friction, for example, according to the physical theory, so ably expounded by Tyndall, that heat is a vibratory motion amongst the molecules of matter, the resistance arrests, to a certain degree, the motion of *masses* of matter rubbed against each other; but the visible motion so disappearing, is transferred to the *molecules*, and so causes the invisible motion known to us as heat. The frequency of these vibrations increases in proportion to the sensible heat produced.

Quantities of Heat developed by the Chemical Process of Combustion.

In order to be able to determine the relation between chemical force and mechanical work, it remains to be ascertained what is the amount of heat evolved by the combination of proportional quantities, or atomic weights, of two or more elementary substances. The heat evolved in the combustion of charcoal with oxygen, is thus measured, the heat itself being supposed to be the result of an almost infinitely rapid motion of the combining molecules, through almost infinitely minute distances. Experiments made on the amount of heat imparted to water in a calorimeter, have established the fact, that very different amounts of heat are given off by burning equal weights of different combustible bodies. The mode of estimating these varying quantities is, by measuring the heating effects produced by the combustion in oxygen, of 1 gramme weight of each substance, upon the standard gramme of water employed in the calculation of the heat-units. (Favre and Silbermann.) In this way, 1 gramme of carbon, in combining with oxygen in the act of perfect combustion, to form carbonic acid, evolves as much heat as will raise the temperature of 8080 grammes of water 1° Cent.; in other words, it evolves 8080 heat-units. Again, 1 gramme of hydrogen, in uniting with oxygen to form water, evolves 34,462 heat-units. Now, carbon and hydrogen are the two chief combustible or oxidizable elements of the food, the blood, and the solid tissues; the nitrogen passes out of the body unoxidized, but combined in the urea. Most of the carbon and hydrogen escape from the system completely oxidized, as carbonic acid and water; but some of each of those elements, especially of the carbon, appear combined with a little oxygen, and also with the nitrogen in the urea. Moreover, the quantity of heat given out by combustible bodies appears to be the same, whether they are oxidized slowly or rapidly. The physical data just explained may therefore be applied to the quantitative examination of the relations between the chemical changes occurring in the human body, and the amount of mechanical and calorific work performed in it.

Calorific Work of the Body.

The number of heat-units given off by a dog in 24 hours, having been ascertained to be 393,000, the number evolved, in the same time by a Man weighing seven times as much as the dog, would be 2,751,000 heat-units. (Despretz.) From calculations of the number of heat-units given off by the body in various ways—by radiation, by evaporation of water, and by the warming of the respired air and excreta—it has also been estimated that the daily loss, and therefore the daily production of heat by it, amounts to 2,700,000 heat-units. (Helmholz.)

Comparison of the Daily Amount of the Animal Heat, with the Quantity of Carbon and Hydrogen oxidized in 24 Hours.

Now the quantity of carbon in the daily food, according to Table A, at p. 901, is 9.93 oz. or 281.2 grammes; the quantity of hydrogen not already combined with its due proportion of oxygen in the carbhydrates is 0.64 oz. or 18.86 grammes. Deducting from these the quantities of those elements contained in the urine and solid excreta, Table B, viz., 1.05 oz. or 29.8 grammes of carbon, and 0.2 oz. or 6.3 grammes of hydrogen, there remains a residue of 251.4 grammes of carbon, and of 12.56 grammes of hydrogen, free for conversion into carbonic acid and water. The 251.4 grammes of carbon, multiplied by its heat-coefficient 8080, produce 2,031,312 heat-units; whilst 12.56 grammes of hydrogen, multiplied by its heat coefficient 34,462, give 432,842 heat-units, the total being 2,464,154 heat-units. (Vierordt.) This calculation shows a deficit in the heat, derivable from the combustion of the daily food, as compared with that given off daily by the body, of about 286,800 heat-units, or about $\frac{1}{10}$th only of the total estimated quantity of heat given off in the day. It has been supposed that the heat evolved by the sulphur and phosphorus oxidized in the body, would go far to meet this deficit. But in 120 grammes of albumen, the supposed daily supply, there are only 1.4 grammes of sulphur; and, as the heat-coefficient of this element is 2307, the heat from that source, provided all the sulphur were oxidized, which is not the case, would only amount to about 32,300 heat-units; the phosphorus would yield a somewhat smaller number. Moreover, there are considerations which would appear to make the deficit still worse. Thus, although the hydrogen of the starchy food is excluded by Vierordt, because, being present with oxygen in the proportions to form water, it is probably already so combined, and therefore unable to evolve any further heat of combustion, yet no deduction is made for such hydrogen as may be balanced by the oxygen in the fatty and albuminous food. In this fat and albumen, besides the oxygen which passes out with the urea and the solid excreta, sufficient exists to unite with, and so neutralize, about 2 grammes of hydrogen; and if it be so combined, a loss of heat power must be admitted of about 68,900 heat-units. A small quantity of the carbon and hydrogen of the food also disappears unoxidized as carburetted hydrogen. It is furthermore usually maintained, that a certain quantity of chemical action is transformed into external mechanical work, without being converted into heat in the body; and this quantity has been estimated as high as 235,000 heat-units. From these circumstances, the total deficit in the heat-units of the food as compared with those supposed to be given off from the body, would be 500-000, *i. e.*, between $\frac{1}{5}$th and $\frac{1}{6}$th of the daily heat.

This discrepancy may, however, be fully explained by possible errors in the larger data. Thus, the estimated weight of the human body, and therefore the number of heat-units producible by it, in proportion to the particular dog experimented upon, by Despretz, may be too large; or the daily supply of carbon and hydrogen in the food may be underrated for a man of the estimated weight. Vierordt himself elsewhere assumes only 2,500,000 heat-units as the average daily quantity evolved by an adult; and the same number has been accepted by Carpenter as the probable number for a man weighing 180 lbs., *i. e.*, much above the average standard. The adoption of this number would reduce the deficit to 300,000 heat-units, which would be provided for by a daily addition of 37 grammes of carbon in the food, a quantity which would be contained in 3 oz. of starch, or $1\frac{1}{3}$ oz. of fat. According to Playfair's Tables (p. 920), such an additional quantity is actually consumed. The results of improved methods of research and calculation, therefore, quite support Lavoisier's chemical theory of animal heat.

Mechanical Work of the Body.

The daily working power of a Man, and the actual mechanical work done, according to his individual strength, must vary greatly according to the exercise or labor he undergoes. It is said that a Man can raise 100 lbs., 1 foot in a second, for 8 or 10 hours in the day; that, on level ground, he can draw 640 lbs. weight; that he can lift 286 lbs. with both hands, and support on his shoulders, 330 lbs. The daily work of a Man is said to be between $\frac{1}{7}$th and $\frac{1}{8}$th of that of a horse. More exact computations show, that with severe labor, the daily work of a man is equal to 207,871 met. kils., or 1,500,000 ft. lbs. (Ranken); with moderate labor, it is not more than 66,518 met. kils., or 480,000 ft. lbs. (Ranken.) The work performed by pedestrians has been estimated at 109,570 met. kils., or 790,720 ft. lbs. (Haughton). In marching, a soldier exercises a tractive force equal to $\frac{1}{20}$th of the weight of his body, arms, and accoutrements. The coefficient of traction is, therefore, expressed as being $\frac{1}{20}$th of the weight to be moved; hence, a soldier weighing 150 lbs., with 60 lbs. of weight to carry, and marching 14 miles per day, performs work equal to 107,560 met. kils., or 776,160 ft. lbs. (Playfair).

Thus 150 + 60 ÷ 20 lbs. × 14 × 5280 feet = 776,160 ft. lbs.

The mean of 9 estimates of laborious work, according to various authorities, is 105,605 met. kils., or 762,048 ft. lbs. This represents the daily *external* mechanical work of the body. Of the *internal* mechanical work, a large portion, which is usually referred to the external work, is that which poises the body and supports it. Next to this, is the true internal work, of which the most is performed by the heart, which has been estimated by one authority at 37,871 met. kils., or 273,280 ft. lbs. (Haughton); and by another at 70,000 met. kils., or 492,520 ft. lbs. in 24 hours; the daily work of the left ventricle alone, is estimated at 46,000 metre-kilogrammes. (Vierordt.) Another estimate gives 43,000 met. kils. for the left ventricle, and 21,000 for the right ventricle, making a total of 64,000. (Donders.) According to the lowest estimate, the work of the heart, which is always beating, is equal to more than $\frac{1}{3}$d, and, according to the highest, to nearly $\frac{2}{3}$ds of the total daily external work. Taking the highest estimate of the heart's work, and adding it to the mean labor-work of Man, as above estimated, we arrive at the sum of about 175,600 met. kils. To this must also be conjoined the work of respiration, *i. e.* of the diaphragm and the intercostal muscles, 63,000 met. kils. (Donders), the work of the digestive organs, and other internal mechanical work, which will probably raise the total daily mechanical work, external and internal, performed by a man engaged in active employment, to the sum of 250,000 met. kils. From other calculations, Vierordt adopts 200,000 met. kils., but exclusive, as it would seem, of the internal work. Again, the actual mechanical effort, or work, accomplished by a muscle, is equal to the product of the weight lifted, multiplied by the height to which it is lifted. Thus, with a frog's muscle, Weber found that 5 grammes were lifted 27.6 millimetres, 15 grammes 25.1 mm., 25 grammes 11.45 mm., and 35 grammes 6.3 mm. The products of these numbers, showing the work accomplished in each case, are respectively 138, 376, 286, and 220 *gramme-millimetres*. Hence, although the work effected at first increases with the load, it soon reaches a maximum, and then diminishes. Since every muscle becomes exhausted by work, and requires intervals of rest for reparation, it is necessary, in order to determine the actual mechanical work accomplished by a man or animal, to take into account the element of *time*. In this way, it has been estimated that the mechanical work of a Man is represented by 7 met. kils. per second, and that of a horse, by from 60 to 70 met. kils. Allowing 8 hours' work out of the 24, the daily work of a Man would be 201,600 met. kils. (Redtenbacher.) The average work per second, throughout the day, would be 2.3 met. kils.

In the steam engine, the amount of heat evolved by the fuel consumed, is sometimes 30 times, and, in the most economical engines, 20 times, greater than the quantity converted into useful mechanical work; theoretically, the utmost available mechanical power is only $\frac{1}{10}$th part of that producible by the heat of the coal consumed. But in the human body, the economy of combustible material is much greater. The total amount of heat given off from the body, in 24 hours, has been shown to be from 2,500,000 to 2,750,000 heat-units. The former or smaller quantity would lift a corresponding number of grammes, or 2500 kilogrammes, to a height of 424 metres; and would, therefore, yield a mechanical equivalent of about 1,060,000 met. kils., or about 5 times as much as that which is requisite for the total daily work, viz., 250,000 met. kils. Whilst, therefore, in an engine $\frac{1}{20}$th part only of the fuel consumed is utilized as mechanical power, $\frac{1}{5}$th of the food absorbed by Man is so appropriated. This latter proportion agrees with Helmholz's calculations.

Relations of the Kinds of Food, to the Modes of Work.

The calorific and mechanical work of the body, being thus understood to have their immediate source in the power stored up in the food, and in the oxygen of the air, and which is set free on the occurrence of chemical combination between them, after such food is assimilated into blood or tissue,—it may be admitted that, allowing for certain errors of calculation and deficiencies of knowledge, the numerical or quantitative method shows that sufficient matter is oxidized in the body, to account for *both* those modes of work. It must, however, next be inquired, what are the relations of the *different kinds of food* to these *two different modes* of work.

It has long been observed that the carbon in the carbhydrates and hydrocarbons, or amyloids and oleoids of the daily food, greatly exceeds that contained in the nitrogenous or albuminoid food. In Table A, p. 901, the ratio is shown to be 7.64 to 2.29, or rather more than 3 to 1; the number of heat-units developed by the former would of course be proportionally large. If to this carbon be added the hydrogen not united with oxygen, this portion of the food seems to be the obvious source of *calorific* power in the body. Vierordt remarks, indeed, that, if from the carbon and hydrogen of the nitrogenous food, enough of those elements be deducted to form the urea excreted by the kidneys, a quantity remains, totally insufficient to develop the heat-units necessary for the calorific work; for then only 57.3 grammes of carbon and 6.3 grammes of hydrogen, will be left, which, multiplied by their heat coefficients 8080, and 34,460, yield a total number of 680,082 heat-units, which is only about $\frac{1}{4}$th of the required daily amount, viz., 2,500,000. The non-nitrogenous food, in accordance with the general opinion, is therefore, regarded as the essential source of the *animal heat*. Indeed, 22 oz. of starch alone, not an unusual quantity in certain daily dietaries, Tables, p. 920, would yield, 2,187,000 heat-units.

As regards the *mechanical work*, it is well known that this, whether internal or external, involuntary or voluntary, is performed through nervo-muscular action; that this implies fatigue and waste of the muscular and nervous substance; that so long as muscular contractility lasts, so long do oxidation changes go on in a muscle (G. Liebig); that a due supply of oxygenated blood is necessary for the continuance of this contractility; and that the quantity of carbonic acid contained in the venous blood returning from muscles, is in direct proportion to their activity. It is further certain that the muscular and nervous tissues must be largely supplied by the nitrogenous or albuminoid portion of the food. From these facts, it might well be inferred, that the mechanical or nervo-muscular work of the body, has its immediate source in the transformation and oxidation of the muscle itself, and, therefore, in the so-called histogenetic, plastic, or flesh-forming nitrogenous food. The opinions and practice of agriculturists, railway contractors, and trainers of men destined for athletic sports, further indicate, that a proportional increase in the quantity of flesh-forming food, is believed to be necessary for animals or men engaged in severe or protracted labor.

The teaching of Liebig, on these points, is indeed very precise and decided. According to him, the hydrocarbons and carbhydrates are the exclusive heat-formers; whilst the sole source of mechanical power, is the oxidation of the nitrogenous substance of the muscles and nerves, built up again by the albuminoid or plastic constituents of the food. These views have been very generally accepted, and have been especially supported, amongst others, by Ranke, Draper, Playfair, and Odling. Draper says of muscular contraction, that it may be supposed to be due to disintegration of the sarcous particles, and that the transformation of muscle by oxidation, may be the condition of muscular action. Odling regards the combustion of the carbon and hydrogen of fat, as liberating a force exhibited solely in the form of heat; whilst the combustion of an equal quantity of the carbon and hydrogen of voluntary muscle, is expressed chiefly in the form of *motion*.

Playfair has endeavored to show, on numerical grounds, that although the chemical combination of the carbon and hydrogen of the albuminoid food, with oxygen, is insufficient to account for the calorific work, yet it is adequate to produce the mechanical work of the body. Hence he concludes that it is the ultimate magazine of force, for the production of its dynamical operations. The following are the principal facts and arguments to which he directs attention.

From numerous English and foreign sources, he has collected a series of dietaries actually in use, under various conditions of rest or work, of which the annexed Table A, gives only the mean results. The *starch equivalent* includes the actual starch of the food, together with the carbon and hydrogen of the fat, expressed as starchy matter, 1 part of fat being considered equal to 2.4 parts of starch. The *subsistence diet*, is that which is considered necessary to support life in a condition of rest, or the diet necessary for the vital mechanical work of the body; it is illustrated by the convalescent diet of hospitals, and by the low diets of ill-fed persons. The diet needful for active employment in health, is represented by the diet of soldiers during peace. An improved diet necessary for more arduous work, is that given to soldiers during war. The diet of active laborers, is exemplified in that of the corps of Royal Engineers engaged in civil employment. Lastly, a still fuller diet, is that of laborers and others employed in yet more continuous and heavy work.

A. Mean Results of Dietaries in oz. Avoirdupois.

	Flesh-formers.	Fat.	Starchy substances.	Starch equivalent.	Salts.	Carbon and flesh-formers.	Carbon and heat-givers.	Total Carbon.
Subsistence diet, .	2.33	.84	11.69	13.68	—	—	—	7.469
Soldiers' diet during peace,	4.215	1.847	18.69	22.059	.714	2.267	9.72	11.987
Do. during war,	5.41	2.41	17.92	23.48	.68	2.9	9.81	12.71
Do. in civil work,	5.08	2.91	22.22	29.38	.93	2.73	12.113	14.844
Diets of laborers, .	5.64	2.34	20.41	25.97	—	—	—	13.89

B. Average Quantities in oz. of Different Food Constituents, consumed under different conditions of Rest and Work (PLAYFAIR).

Food Constituents.	Subsistence diet.	Diet in quietude.	Diet of healthy adult.	Diet of active laborers.	Diet of hard-worked laborers.	Addition required for active laborer.
Flesh-formers, . .	2.0	2.5	4.2	5.5	6.5	3.5
Fat, ...	0.5	1.0	1.8	2.5	2.5	2.
Starch, ...	12.0	12.0	18.7	20.0	20.0	8.
Starch equivalent, .	13.2	14.4	22.0	26.0	26.0	12.8
Carbon, ...	6.7	7.4	11.9	13.7	14.3	7.

The *subsistence* diet in Table B, is supposed to show, amongst other facts, the quantity of albuminoid food consumed in the performance of the absolutely *essential internal* mechanical work of the body, when at complete rest. Taking this as a *datum* quantity, the additional amounts consumed in quietude, in full health, in active labor, and in hard labor, are .5, 2.2, 3.5, and 4.5 oz. In extreme labor, the quantity of flesh-formers, is, therefore, more than trebled, as compared with the subsistence diet. The starch equivalent is also increased, being, however, only doubled. This increase, Playfair considers as coincident with the additional animal heat given off in increased exertion, during which all the functions, digestive, assimilative, circulatory, and respiratory, are much excited. An increased consumption of non-nitrogenous food is not only demanded by an increased waste of the nitrogenous tissues, but it may even cause the latter, by exciting the animal functions. As, for an active laborer, 3.5 oz. seems to be the additional amount of albuminoid food needed beyond the subsistence diet, so a horse, when at work, is said, by Playfair, to consume 27 oz. more nitrogenous food than when at rest. The proportion between these superadded quantities, in the Man and the horse, is about 1 to 7½, and, as already mentioned, the horse's daily work is estimated as being equal to that of 7 or 8 men. It is further stated, that the work of a horse is to the work of an ox, as 1.43 to 1; whilst the total albuminoid food consumed by those two animals, when engaged in labor, is as 1.46 to 1. In animals fed exclusively upon a flesh-diet, allowance being made, when necessary, for the fat contained in it, Bischoff, Pettenkofer, and Voit, found that the carbon excreted in the urea, is about $\frac{1}{7}$th of the quantity given off in the form of carbonic acid; hence Playfair supposes that 1 part of albumen, if oxidized by 100 parts of oxygen, may be transformed into 3.1, or about 3 parts, of urea, which would contain 3 of carbon, into 21 parts of carbonic acid, which would contain 21 of carbon, and into 13 parts of water. The carbon in the urea and carbonic acid is, here also, as 1 to 7. Urea itself is regarded as a compound of carbonic oxide and ammonia, and its carbon, as being only partially oxidized. Of the hydrogen, three-fourths are deducted, as being either already combined with oxygen, or as belonging to the ammonia. The heat-units are accordingly calculated for so much carbonic acid, carbonic oxide, and water, and also for sulphuric acid formed by the sulphur of the albumen. One ounce of albumen, 437.5 grains, or 28.35 grammes, if thus decomposed, would yield 126,500 heat-units, the mechanical equivalent of which is 53,762 met. kils. Hence the 2 oz. of flesh-formers in the subsistence diet, would afford 107,524 met. kils. of work, which exceeds the essential vital work performed in the body in the condition of convalescence, the work of the heart representing the largest item of the internal mechanical or vital work, being taken at 37,781 met. kils., which, however, is too small an estimate. Again, the 3½ oz. of additional albuminoid food consumed by the active laborer, are mechanically equivalent to 188,167 met. kils.; whilst the mean amount of laborious work is only equal to 105,605 met. kils. Lastly, the 5¼ oz. of albuminoid food consumed by the active laborer, yield 295,691 met. kils.; whereas his total mechanical work, external and internal, is, as we have seen, only 250,000 met. kils. Even if each of the above-mentioned mechanical equivalents of the albuminoid food be reduced by one-twelfth, for that which passes off in the solid excreta without undergoing combustive change, still, in each case, enough power remains, derived from the oxidation of the albuminoid food, to execute the mechanical work, whether internal or external, performed by the body.

It is maintained by Playfair, that the blood cannot be the source of the motor power, but this opinion is open to question. The quantity of fat in muscular tissue, only 2 per cent., is too small to accomplish it. The fat in the heart could only yield 10,157 met. kils., whilst the work of the heart is estimated as equal, at least, to 37,780 met. kils. In 4 oz. of dried flesh, there would be 150 grains of fat, which would yield 36,888 met. kils., whilst that amount of muscular substance itself would yield 214,544 met. kils. The fat of muscle being therefore wholly inadequate to produce the mechanical work, it is presumed, by Playfair, that the larger quantity yielded by the muscle itself, must be regarded as its source. Moreover, the fatty substances, as we know, are wanted for heat-giving purposes. They are required, we may add, to supply the waste of the nervous substance in muscular action; and the fat in the muscles may protect them from oxidation, when no movement is taking place; but fat alone cannot act vicariously as a substitute for albuminoid food. In starving animals, the fat wastes gradually day by day, undergoing oxidation at an equal daily rate, whilst the muscle wastes irregularly, at first slowly, then more uniformly, but, at the approach of death, very slowly indeed, the mechanical work, external and internal, being reduced to a minimum.

The amount of albumen allowed in the dietary of Vierordt (p. 901), after deducting the urea, and $\frac{1}{12}$th for loss by the solid excreta, would yield 680,000 heat-units, or a mechanical equivalent of 264,152 met. kils., a quantity closely corresponding with the amount obtained by Playfair's calculations, and likewise exceeding the estimated total daily mechanical work of 250,000 met. kils.

The small balance of unemployed force is regarded by Playfair as proving the extreme economy of the operations of the living body. If, indeed, the mechanical work derived from the chemical energy developed in the oxidation of 3½ oz. of excess of albuminoid food, viz., 188,167 met. kils., be compared with the external mechanical work of an actively employed laborer, 105,605 met. kils., the proportion of actual work to the total producible energy is about as 1 to $1\frac{4}{5}$. In comparing the total work performed, 250,000 met. kils., with the total heat produced from all the food, 295,691 met. kils., more than $\frac{5}{6}$ths of the chemical energy developed are utilized, instead of $\frac{1}{5}$th, as estimated by Helmholz, and others, and instead of $\frac{1}{20}$th, as is the case in the best steam-engines. Every particle of energy developed in the body is probably, in some way, usefully employed.

The researches of the Rev. Dr. Haughton on excreted products, taken as the measure of work, bear on this question of the source of motor power in the body. By determining the quantities of urea excreted by the kidneys, under different circumstances of rest and labor, he endeavors to ascertain the potential energy represented by the urea, considered as a product of the decomposition of the albuminoid tissues. The work of the body is classified, by him, into vital, mental, and mechanical. These he supposes to be represented respectively, by the daily excretion of 297, 217, and 136.5 grains, making a total of 650.5 grains of urea; the total daily amount excreted by a person engaged in very active bodily and mental work is, therefore, 650.5 grains. In routine labor, he infers that 400 grains of urea are sufficient to represent the vital and mechanical work; but, in higher work, he allows 533 grains of urea; and regards 575 grains as the average for a healthy actively engaged adult. As 1 part of urea represents 3.1 parts of dried albumen, this daily average quantity of urea, viz., 575 grains, represents 3.9 oz. of dry albuminoid food; 400 grains, 2.8 oz.; and 650 grains, 4.3 oz. This quantity is thus apportioned by Haughton: for the vital work, 297 grains, representing 2 oz. of albumen; for the mental work, 217 grains, representing 1.4 oz.; and for the mechanical work, 136.5 grains, representing .9 oz. To raise these quantities into the actual quantities of albuminoid food consumed, $\frac{1}{12}$th more must be added, in each case, for the albumen eliminated, unchanged, in the solid excreta. Then it will be seen that the quantity of urea taken to represent the vital work, is more than equal to the flesh-formers in the subsistence diet of Playfair. But the quantity said to correspond with the external mechanical work is insufficient, representing, even with an addition of $\frac{1}{12}$th, less than 1 oz. of albuminoid food; whilst the mechanical work of an active healthy adult demands, according to Playfair, an extra quantity of 2.2 oz. of flesh-formers beyond the subsistence diet. The large quantity allotted to mental work is perhaps excessive, and may supply the deficiency; for the quantity of albumen corresponding with the total amount of urea is 4.4 oz.; this, with its superadded $\frac{1}{12}$th, would more than equal the full diet of Playfair, though it would not approach the 5.5 oz. diet of the active, much less the 6.5 oz. of the hardworked, laborer.

But the estimates of Haughton as to the quantity of urea excreted daily under conditions of labor, are less than the quantities which have been observed by others. The quantity in convalescence, and in cases of starvation or hunger-cure, ranges from 263 to 300 grains; the average quantity in health appears to vary from 560 to 580 grains; and the quantity excreted daily, by hardworked laborers, has been found to differ, according to their work and *food*, from 600 to 700 or 800 grains. In Hammond's experiments on himself, whilst without exercise, the quantity of urea excreted daily was 487 grains, and of uric acid 24.9 grains,—the quantities of those two substances excreted in moderate exercise, were 682.1 grains, and 13.7 grains; and, in hard exercise, as much as 865 grains, and 8.2 grains. The quantity of urea which corresponds with 5.5 oz. of albuminoid food, the active laborer's diet, is 735 grains. The estimates of Haughton are evidently low; if augmented, in accordance with the observations of others, as to the increase in the urea excreted during full exercise, *and with a full diet*, they might, at first, appear to harmonize with the view, that the chemical energy developed by the oxidation of the albuminoid food, is the source of all the mechanical work performed in the body. The production of the urea is not supposed, by itself, to develop the energy required; but this substance is an index to the quantity of albuminoid substance oxidated, in the body, into urea, carbonic acid, water, and sulphuric acid. This urea can be easily separated and weighed; but the carbonic acid and water, derived from the partial oxidation of the albuminoid food, mixing with the much larger quantities derived from the carbhydrates and hydrocarbons, completely escape measurement.

But the theory of Liebig (1842–51), as to the special source of the motor power of the system, thus illustrated by arguments and calculations, derived from an advanced state of knowledge concerning the relations between chemical action, heat, and motion, is opposed by many authorities, especially by Mayer, Traube, Donders, Heidenhain, more recently by Fick and Wislicenus, and, in England, by Lawes and Gilbert, and by Frankland. The experiments of Lehmann, Ed. Smith, Voit, Bischoff, Speck, and Dr. Parkes, have assisted much to elucidate this subject.

It was long ago maintained by Mayow, of Bath (1681), that, for the occurrence of muscular action, combustible material, fat, must be conveyed by the blood to the muscles, together with some principle derived from the air in respiration. According to Mayer, of Bonn (1845), an early observer in the field of quantitative research as regards heat and its relations to other forms of force, a muscle is not the material by the chemical change of which, mechanical work is produced; but an apparatus by means of which, the transformation of force is accomplished. If the former were true, he argues that the heart would be completely oxidized, in doing its own work, in 8 days. He believes the capillaries of the muscle to be the seat of the actual changes, and the blood to be the fuel consumed. Traube also has distinctly taught that the substances, by the burning of which, force is generated in the muscles, are not the albuminoid constituents of those tissues, but non-nitrogenous substances, either fats or carbhydrates. Donders and Heidenhain coincide in these views.

It has, moreover, been found that the amount of urea excreted is regulated, not so much by the exercise taken, as by the quantity of albuminoid food which is consumed. Hence much of this substance must be formed independently of the metamorphosis of muscle; and therefore Haughton's estimates of it, as a measure of work, become seriously invalidated. Lastly, much uncertainty prevails, as to the accuracy of the data employed for the calculations of the heat given off in the oxidation of albuminoid food, and, therefore, as to the correctness of the deductions from them, made by Vierordt, Playfair, and others. Thus Lawes and Gilbert (1852) observed, that of two pigs fed, one on lentils, which contain 4 per cent. of nitrogen, and the other on barley, which contains only 2 per cent., the excreta of the former yielded twice as much nitrogen as those of the latter; from which they infer that the quantity of urea excreted *i. e.*, of albuminoid substance decomposed, is no guide to the amount of work done, the exercise taken having been the same in each case, but that it depends on the quantity of nitrogenous food consumed. They, moreover, conclude that some of the muscular power depends on the oxidation of non-nitrogenous substances. Again, the researches of Edw. Smith, Voit, Lehmann, Bischoff, and Parkes, indicate that the urea excreted bears no definite relation to the labor performed; and that in prolonged exercise, the increase of urea is very small. The effects of treadwheel labor serve only to increase the quantity of urea, by 19 grains in 24 hours, as compared with that eliminated in easy labor. (Smith.) In fasting animals, the effects of increased exertion are also very slight as regards the urea, and seem to be regulated by the periods of ingestion of water, and by the increased respiration and circulation, rather than by the direct waste of the voluntary muscles. (Voit, Bischoff.)

Lastly, the experiments of Dr. Edw. Smith prove, on the other hand, that the production of carbonic acid does increase, strictly in accordance with the exercise taken. During sleep, the quantity exhaled in an hour was, in his own case, 19 grammes; whilst lying down before sleep, 23; in a sitting posture, 29; whilst walking two miles an hour, 70.5; in walking three miles an hour, 100.6; and upon the treadwheel, lifting his body, 28.65 feet in a minute, as much as 189.6 grammes per hour.

The recent observations of Fick and Wislicenus, on the results of a certain amount of work performed by themselves, also point to the conclusion, that muscular effort, on a *non-nitrogenous* diet, does not increase the quantity of urea excreted from the body; moreover, they conclude that the oxidation of the quantity of albuminoid substance, or plastic nitrogenous material, which would correspond with the urea and other nitrogenous compounds then excreted, does *not* yield sufficient potential energy to perform the work accomplished. The mechanical work undertaken by them, was the ascent of the Faulhorn, a mountain in the Bernese Oberland. From the middle of the day before, until the ascent was completed, no albuminoid food was taken, so that no excess, or *luxus consumption*, might interfere with the experiment. During 11 hours of the night previous to the ascent, the quantities of urea excreted by them respectively, were by Fick, 12.5, and by Wislicenus, 11.75 grammes. During the 7 hours and 40 seconds occupied in the ascent, or *work-hours*, *i. e.*, from 10 min. past 5 A.M. to 20 min. past 1 P.M., the quantities were 7. and 6.7 grammes. During the next 5 hours and 40 min. of rest, or *after work*, in which an abundant meal of meat was consumed, the quantities were 5. and 5.1 grammes. The quantity of urea excreted per hour was, therefore, *not* increased *during exercise on a non-nitrogenous diet*. In determining the relation between the quantity of albuminoid substance decomposed, and the mechanical work performed, they take into account not only the urea, but the whole nitrogen eliminated in a more or less oxidized form, and they find that this, during the actual period of *work*, would represent in F. 22.098, and in W. 20.89 grammes of albumen. The minute trace of nitrogen given off from the skin is neglected, and so is the larger quantity contained in the fæces, because it passes off in almost unoxidized compounds. The possible retention in the system of some partially oxidized albuminoid substances, such as creatin, is admitted; but to compensate for this they add a quantity of albumen, equal to the nitrogen excreted in the period of *after work*, making the respective totals, 37.17 and 37. grammes of albumen oxidized. The heat given out by the oxidation of these quantities in the body, is unknown; but from avowedly imperfect data, and making the fullest possible allowance, they conclude that the energy obtainable from its oxidation might be for F. 250,000, and for W. 249,000 heat-units; giving respectively 106,250, and 105,825 met. kils. of mechanical power. Now the chief work actually performed by them, was lifting the weights of their bodies, as clothed, through the height of the mountain; this is measurable by multiplying the former by the latter. Thus F. exerted a force of 66 kil. × 1956 metres = 129,096 met. kils., and W. a force of 76 kil. × 1956 metres = 148,696 met. kils.; if to this be added the internal work of respiration and circulation, the totals are, for F. 159,637, and for W. 184,287 met. kils. These results show, therefore, that the mean work performed, in proportion to the power derivable from the oxidized albumen, was as 3 to 2. It is well known, however, that much other work is performed in the exercised body, which does not contribute directly to the external work performed; and Heidenhain has computed that only one-half the energy of the force-generating processes, is really used as work. Hence, double the amount of work was actually performed in the bodies of F. and W., or 319,274 and 368,574 met. kils.; in other words, the ratio of work performed to the power derivable from the consumption of albuminoid substances in the body, was as 3 to 1. Since, therefore, it is impossible for the oxidized albumen to be the sole and exclusive source of the power manifested in the work of the body, to which it can contribute so little, they conclude that the oxidation of non-nitrogenous substance must yield, at least, the larger proportion of the force required, not only for the production of heat, but also of mechanical motion. Moreover, since it is improbable that, in so delicately an organized apparatus as the muscular tissue, two sorts of decomposition should occur, for the purpose of liberating the same force, they believe that, as non-nitrogenous substances *are* decomposed *for that purpose*, *those only* are decomposed. The nitrogenous substances of the muscle, however, simultaneously undergo waste or wear, and thus yield urea. In conclusion, they show that the resemblance of the living animal body to a steam-engine, is more close than is usually admitted; the muscle is an apparatus for burning its appropriate fuel, the hydrocarbons and carbhydrates, in the same manner as an engine burns its proper fuel, coal or coke; in action, the muscle does not specially oxidize itself, any more than the engine is burnt; but in action, both the muscle and the engine undergo wear. In use, the wear, in either case, is not much increased, but the consumption of fuel is decidedly greater. It is possible, they remark, either that non-nitrogenous substances in the muscle act as the combustibles, or that they pass through the muscle in a *rapid stream*, their particles being immediately oxidized, and then carried away.

The general conclusions of Fick and Wislicenus are strengthened by the subsequent researches of Dr. Frankland, who has also supplied more secure data for estimating the heat-units produced by the oxidation of albuminoid substances in the body. It was admitted by the German physiologists, that these could not be equal to the heat-units evolved by the combustion of the separate elements of albumen out of the body, although they allowed that quantity in their calculations. By mixing a certain quantity of *muscle* deprived of fat, *albumen*, and *urea*, all dried at 212° F., with chlorate of potash. deflagrating the compounds, and measuring the heat evolved, by its effect in raising the temperature of water, Dr. Frankland shows that 1 gramme of each of these substances respectively evolves, 5103, 4998, and 2206 heat-units. Now, as the muscular substance is imperfectly oxidized in the body, forming urea, or some still less completely oxidized material, it can only yield the above-mentioned number of heat-units, minus the number producible by the quantity of the imperfectly oxidized nitrogenous substances into which it is converted in the system. Albuminoid bodies, in undergoing decomposition, yield about $\frac{1}{3}$d their weight of urea. Hence, using the above given data, 1 gramme of dried muscle oxidized in the body would yield $5103-\frac{2206}{3}$, or 5103–735 heat-units = 4368 heat-units, or 1848 met. kils. of mechanical power; for 1 gramme of pure albumen, the results are 4263 heat-units, or 1805 met. kils. of force. Applying these data to Fick and Wislicenus' experiments, it will be found that, as they eliminated respectively, nitrogen equal to 37.17 grammes, and 37 grammes of albuminoid substance, the available energy they produced would be only 68,690 and 68,376 met. kils.; whilst their computed work was 319,274 and 368,574 met. kils. The mean ratio of the work performed, to the power derivable from the oxidation in the body of the nitrogenous substance of muscle, was, therefore, less than they had supposed, viz., as 5 to 1.

Again, if the method devised by Frankland, for measuring the energy derivable from the oxidation of albuminoid substances in the body, be correct, then the determinations of Haughton and Playfair are inadmissible. Moreover, applying the same data to the observations of Edw. Smith on prisoners working on the treadwheel, to those of Haughton on men engaged at shot drill, and to those of Playfair on fully employed laborers, Frankland found that the work accomplished was, in the first case, nearly 2 to 1, in the second case, more than 2 to 1, and in the last case, 1.3 to 1, in proportion to the force indicated by the excreted nitrogen; and yet, in each of these cases, unlike the experiments of Fick and Wislicenus on themselves, the food contained a large amount of nitrogenous substances, which increased the quantity of nitrogen eliminated. Fick and Wislicenus intentionally consumed a *non-nitrogenous* diet.

Dr. Frankland agrees with the previous conclusions, that the transformation of muscle tissue is almost entirely independent of the *amount* of work performed; that, in Man, non-nitrogenous substances must be the chief source of the energy which is transformed into muscular work; that the muscle is an apparatus in which this energy is evolved, at the expense of hydro-carbonaceous fuel, or a machine for converting potential energy into mechanical force, and that it does not undergo much more waste when in action, than when at comparative rest. Besides this, he believes that the oxidizable material does not require to be previously organized or made part of the muscle, but only to be digested and assimilated into the blood, of which it forms a part. He conceives that the materials of the food, together with oxygen, circulate in the blood going through the muscle, and that when the latter is quiescent, no chemical action takes place; but that when a muscle is excited to act by a nerve, the nerve force determines the oxidation of non-nitrogenous matters in the blood, and so sets free potential energy, partly acting as heat, and partly as motion. Dr. Frankland admits, however, that nitrogenous matters may also be employed for this purpose, as is illustrated by the work performed by men and animals fed on flesh diet. But ordinary flesh contains much fatty matter.

Dr. Parkes has observed the effects of exercise and rest, under different diets, on the excretion of urea, over longer periods than those noticed by Fick and Wislicenus. His results likewise show, that on a *non*-nitrogenous diet, exercise produces no increase in the excretion of nitrogen; that less urea is excreted during the period of actual work; and that, the elimination of nitrogen, is regulated, rather by the character of the diet than by the amount of exercise. The subjects of observation were two healthy soldiers, whose normal daily standard of excretion of nitrogen, was first ascertained during a period of six days, in which they took their ordinary food and exercise. For two days they consumed non-nitrogenous food, and rested; the urea, and the total nitrogen excreted, then fell to a mean or less than one-half the normal quantity, and yet the men lost weight. They next returned for four days, to their ordinary diet and occupation; the nitrogen excreted, as urea and otherwise, immediately increased from day to day, but did not, on the last day, reach its normal standard; and the total quantity excreted in the four days was less than half of that eliminated in four of the first six days; some nitrogenous food was apparently retained for the nutrition of the tissues, or to supply the nitrogenous blood-material expended in the two days of non-nitrogenous diet. For the next two days, the men again took a non-nitrogenous food, but instead of resting, they underwent full exercise, walking, on the first day, 23.76, and on the second, 32.78 miles; the food satisfied the sense of hunger which was felt; much fatigue was experienced, especially on the second day; the excretion of nitrogen *decreased* during the first thirty-six hours, but in the succeeding twelve hours, which were hours of rest, it showed a marked *increase;* the pulmonary and cutaneous excretions increased, the former 100, and the latter 50 per cent.; the men lost weight. Finally, being allowed their usual diet, with ordinary exercise, the quantity of urea again rose daily, and at last surpassed the normal quantity. The chief difference in these results, as compared with those of Fick and Wislicenus, whose observations were not sufficiently prolonged, is in the increased excretion of nitrogen, during the hours of rest, after severe exercise on a non-nitrogenous diet. This may merely show that the effects of the changes taking place in the muscles during exercise, are slow to manifest themselves in the excreta. The diminution in the nitrogenous excretion, during actual work, on a non-nitrogenous diet, may, as Parkes suggests, be owing to nitrogen being then retained and used, and not to the entire absence of decomposition in the muscular tissues.

In subsequent experiments on this subject, Dr. Parkes found that upon an ordinary mixed diet, containing a daily quantity of about 19.6 grammes of nitrogen, rather less of that element was excreted during the early periods of exercise, and during actual exercise, than during rest, especially during the rest immediately after work, when the quantity rose, so as to be excessive. He suggests a new explanation of the facts, viz., that a muscle increases in size when in action, then appropriating more nitrogen than it loses; but that when it is at rest, it lessens in bulk, losing more nitrogen than it appropriates. Muscular movement is regarded as due to a process of *formation*, and repose as accompanied by disintegration. The non-nitrogenous substances surrounding the ultimate muscular elements, undergo change during the action of the muscle; the effete products, chiefly of those non-nitrogenous substances, as

Ranke and others have supposed, arrest the muscular contraction; a period of rest follows, in which the effete products are removed, and nitrogen is eliminated; and the muscle is once more fit for action. This view explains most of the facts very well; it is also in accordance with experience, as to the necessity of nitrogenous food for persons engaged in prolonged muscular work; and yet it admits that the changes in the nitrogenous elements of muscle, are inadequate to produce the movement, and refers these to the chemical energy evolved by some neighboring non-nitrogenous substances.

The views of Liebig, as to the separate and exclusive sources of heat and motion in the animal economy, are, therefore, controverted by more recent knowledge; it is certainly disproved, that the disintegration of muscular substance is the only source of muscular power; and it is equally proved that, in Man, and probably in Omnivorous animals, the oxidation of non-nitrogenous materials is its chief source. But the chemical powers of the living animal economy have perhaps been underrated; and *à priori* theories may, in both directions, limit too much our notions respecting them. Carnivorous animals, as would appear from the observations of Lawes and Gilbert on fattening animals, of Savory and others, upon rats and dogs fed on a flesh diet exclusively, have the power of splitting up albuminoid bodies into fats and certain nitrogenous compounds. If so, this fat on being oxidized, may become the source of motor power. Besides, as albuminoid bodies are undoubtedly oxidized in the body, they must furnish potential energy transformable either into heat or motion. It seems impossible to believe, with Dr. Frankland, that the *blood only*, and not the nervo-muscular substance also, is oxidized in the production of muscular force; or to deny that nitrogenous substances may also yield *force*, as well as heat. Work is well performed, for a short time, on a non-nitrogenous diet, but fatigue is at last felt, and nitrogenous matter must be wasted; otherwise it would not be retained in unusual quantity, when nitrogenous food is again taken, after a temporary abstinence from it. Nitrogenous food must therefore be supplied, probably, in accordance with the amount of work done. (Parkes.) A muscle may be a machine, and the blood circulating through it, the fuel; but being a living tissue, it, and its nerves, and controlling nervous centres, waste, or they would not become fatigued and exhausted by work. A muscle probably wastes more than a machine wears. This waste may depend largely on the loss of the hydrocarbons, and carbhydrates, in the muscle, and the nerves, yet the more abundant nitrogenous substances in them must likewise participate in the exhaustive process. Before, too, we accept Dr. Parkes' view as to muscular action being accompanied by an absorption of nitrogenous substance, and by growth, it becomes necessary to determine the amount of brain-, spinal-cord-, and nerve-substance, which is consumed, or changed, in all motor acts. This is probably considerable, and possibly largely affects the *fatty matter* of these organs. Might not this oxidation, together with the nutritive changes accompanying it, explain, in part, the increased evolution of carbonic acid during exercise? By occupying the oxygen in the blood, it might also account for there being less to act upon the *muscular* tissue. Yet, we know nothing of the amount of change in the nervous substance considered separately.

The exact destination of the potential energy, liberated by the double process of oxidation of nitrogenous and non-nitrogenous materials, which undoubtedly takes place in muscular motion, cannot at present be precisely pointed out. In Man, the latter substances undergo far more abundant decomposition than the former, and, as remarked by Frankland, whilst the nitrogenous materials are only partially oxidized, being discharged as urea, and retaining about $\frac{1}{7}$th of their potential energy unexpended, the non-nitrogenous substances yield all their energy in the body, being oxidized perfectly as carbonic acid and water.

There are many facts which indicate the necessity for large amounts of non-nitrogenous food, for the due performance of muscular work. It is in the larval stage that Insects generally consume the most albuminoid food, and perform the least amount of work, whilst, in the perfect condition, as in bees, butterflies, and moths, their muscular activity is remarkable, although their food is almost purely saccharine or non-nitrogenous. (Verloren.) The goat, chamois, gazelle, and many other Ruminants, are singularly swift and active creatures; their food, however, is not highly nitrogenous, but chiefly consists of carbhydrates. It is not probable that the muscular work in any of these cases is performed by the oxidation of albuminoid matters only; for, in that event, the muscles, especially the minute ones of Insects, would soon be entirely oxidized, and could not be restored by the scanty supply of nitrogen in the food. The remarkable provisions for digesting the carbhydrates and rendering them absorbable, appear therefore to have reference, not only to their use as heat-givers, but also as sources of motor power. The production of sugar from starch, is a universal action of the saliva of all animals, and long-continued digestion in the Ruminant stomach will even change the cellulose. It has been remarked, that the chief food-manufactures are concerned with non-nitrogenous articles of diet; that eggs contain, when dried, 40 per cent. of fatty matter; that fat is always present in meat; that the poor consume much bacon-fat; and the rich, who eat most albuminoid food, likewise take more butter, sugar, and alcohol. (Lawes and Gilbert.) The use of bacon by the agricultural laborer, has given rise to a familiar epithet for him. The chamois-hunters prefer a store of bacon-fat and sugar, to any other provisions, on a hunting expedition; and Fick and Wislicenus ascended the Faulhorn on non-nitrogenous diet, without special fatigue. But, on the other hand, Parkes found, that on the second day of severe exercise, on a non-nitrogenous diet, healthy soldiers complained of unusual fatigue. Practically, it would seem that sufficient nitrogenous food being supplied for the nutrition of the muscular and nervous system, then the most effective diet for a laborer is that which contains a large proportion of non-nitrogenous substances. Athletes should *train* on meat, but enter into their contests upon amylaceous, saccharine, or fatty food.

Dr. Frankland has extended his method of determining the heat-units by deflagration with chlorate of potash, to various articles of diet, in order to test, in this way, their mechanical equivalents, or *motor values.* The actual energy of a given weight, 1 gramme, of each substance, when burnt out of the body, is ascertained by experiment; and, in the case of albuminoid bodies, the energy which would be developed from them, when oxidized, in the body, is calculated, by deducting the energy remaining in a corresponding quantity of urea. The following Table gives some of the results:

According to this mode of estimating the value of food, as compared with that which regards its composition only (p. 570), cheese still retains a very high position, being inferior only to oils, fats, butter, and cocoa nibs. It appears, moreover, that .55 parts of fat are equal to 1.15 of cheese, to 1.3 of pea meal, to 3.5 of lean beef, and to 5 parts of potatoes.

VALUE OF FOOD AS A SOURCE OF MOTOR POWER (*Frankland*).

Article of Food in natural condition.	Met. Kils. of Force, from 1 Gramme oxidized in the body.	Weight in ozs. required daily, to support the movements of respiration and circulation.
Cod-liver Oil,	3,857	1.5
Beef fat (dry),	3,841	1.5
Butter,	3,077	1.8
Cocoa nibs,	2,902	1.9
Isinglass (dry),	1,914	—
Cheese (Cheshire),	1,846	3.
Oatmeal,	1,665	3.4
Arrowroot,	1,657	3.4
Flour,	1,627	3.5
Peameal,	1,598	3.5
Rice,	1,591	3.6
Gelatin (dry),	1,550	3.6
Sugar,	1,418	3.9
Egg (yolk),	1,400	3.9
" (hard-boiled),	966	5.8
Bread crumb,	910	6.4
Ham, lean (boiled),	711	7.9
Mackerel,	683	8.3
Beef (lean),	604	9.3
Veal (lean),	496	11.4
Stout,	455	—
Potatoes,	422	13.4
Whiting,	335	16.8
Bass's Ale,	328	—
Apples,	273	20.7
Milk,	266	21.2
Egg (white),	244	23.1
Carrots,	220	25.6
Cabbage,	178	31.8

Transformation of Mechanical into Calorific Work in the Body.

Every kind of *internal* work, whether vital, mental, nervo-muscular, or mechanical, electric, or nutritive, excepting the solvent processes, ultimately passes into heat within the body. The purely *external* mechanical work is thought by some, however, to be an exception; but this is not entirely so; it is only the case when motion is communicated to external matter. At the moment of action of a muscle, indeed, an inverse proportion exists between the work accomplished and the heat produced. A muscle develops more heat, when it cannot shorten itself, so as to produce external movement or work; as, for example, when a person attempts to move an overwhelming weight, or overcome an unyielding resistance, as compared with the effect of free action in lifting a movable weight. Any effort or motion which is stopped or resisted, or which disappears in any way, passes necessarily into heat; even the electric currents in muscles and nerves, when they are lessened by disturbance or rest, contribute, however slightly, to raise the temperature of an acting muscle, and therefore of the body. In fever, the muscles may become as hot as 105° Fahr., and in tetanus, 111° Fahr. (Ludwig); they are then hotter even than the blood (Fick); but this happens when most of their chemical energy of decomposition can pass into heat, none being required for work. During muscular action, the chemical energy passes into that *perceptible motion* which we call contraction or shortening; during arrested effort, it appears in the *invisible motion*, which produces heat.

On the supposition that the muscular force is derived from the oxidation of albuminoid substances, the greater part, or the whole of it, is ultimately transformed into heat, and is added to the avowedly larger store derived from the non-nitrogenous food. But the theory which regards animal motion as chiefly, or entirely, derived from the energy supplied by the non-nitrogenous materials of the blood or tissues, and therefore from the non-nitrogenous food, is not inconsistent with the view, that these latter are the calorific or heat-forming materials; for they then serve both offices. The transformation of potential energy into muscular power, whether exerted internally or externally, is necessarily accompanied by the ultimate production of heat within the body; and this is the chief, and probably the only, source of animal heat. (Frankland.)

Nutritive or Assimilative Work.

The assimilative work performed in the body is also chemical, being partly liquefacient, partly dialytic, and partly solidifacient. It must be performed at the expense of chemical energy, developed during the many transformations of the nutritive materials, as these are in turn digested, hydrated, dissolved, absorbed, and converted into tissue. The amount of force employed in digestion is small, as compared with the other great demands of the system. Playfair suggests that it is measurable by the amount of nitrogen of the nitrogenous substances found in the solid excreta; and that it may, as he thought of the mechanical work, be ultimately referable to the energy of the albuminoid food. The quantity of nitrogen which escapes by the lungs and skin is quite unimportant; with ordinary diet, the urea includes $\frac{11}{12}$ths of that contained in the food, whilst the solid excreta yield about $\frac{1}{12}$th. (Ranke.) This small quantity is the residue of the mucus, salivin, pepsin, pancreatin, glycocoll, and taurin of the digestive fluids, the solid constituents of all of which, in a Man weighing 150 lbs., would be upwards of 8 oz. per diem. Playfair supposes that, whilst most of the substances are reabsorbed, a certain portion of each undergoes chemical change, being, as it were, degraded, and becoming unfit for entering the circulation. This remains, therefore, as a quantitative expression of the force which has been employed in the processes of primary assimilation. It may be a residual index of such actions, but not a source of power itself, for it escapes unoxidized. All nutritive work, implying solidification of material, likewise ultimately passes into heat.

Electrical Work.

The currents of electricity developed in the body generally, those found between the arterial and venous blood, in muscle and in nerve, in secreting and in special electric organs, are developed through chemical action, involving waste by oxidation of the blood or tissues, and indirectly therefore of the food, whether of the nitrogenous or non-nitrogenous food, or of both is not yet determined. They do not appear to be derived from friction, changes of temperature, or magnetism, as in the inorganic world. The chemical energy of the body, thus diverted to electric work, cannot, however, be expressed in numbers. Unless it passes off to surrounding objects or media, it is converted into heat, or into motion and heat, within the frame, and so assists in the calorific work.

Nervous Force and Work.

As elsewhere mentioned (p. 227), there exists in nervous substance a peculiar electro-polar condition of the nervous molecules, which is altered, not merely by the passage of an ordinary electric current through a whole nerve, as is the case with the muscular current, but also when that current, or any other stimulus, traverses a small portion of the nerve. The existence of nervous substance is essential to the manifestation of this peculiar condition; the force concerned in its production may be itself what is called the nerve-force, or it may be transformed into that force, serving in either case, to excite the contraction of a muscle, on the one hand, or the reflex or sensitive excitability of a nervous centre, on the other. The reaction of a reflex nervous centre may also require, or depend upon, such molecular polarity. Even sensation, and the higher and purely mental processes, are associated with, and rest upon, similar molecular conditions and properties. The special condition of the nervous matter which accompanies sensation, emotion, thought, consciousness, and will, is unknown to us; but the molecular polarity of the nerve-substance is, as much as the nervous substance itself, a part of the constitution of the living animal body. The polar condition of the nervous molecules represents a portion of the vito-physical work of the system; and variations in it are associated with changes in the nervous matter itself. These changes are chemical, and imply waste, oxidation, and renovation. All nervous action, or work, requires both food and air, containing stores of force, which, exhibiting itself first in chemical combination, is transformed into the electro-polarity proper to, and manifested only by the nervous substance built up within the bodies of animals, and capable of being excited by appropriate stimuli.

The portion of nervous work, performed in the control of the various muscular acts, voluntary or involuntary, and belonging to the animal or vegetative functions, cannot, at present, be dissociated, in any calculations, from the muscular work itself. As to the nervous work connected with sensation and other psychical actions and reactions unaccompanied by motor results, it is impossible, at present, to measure them, and Haughton's allotment of the so-called *mental work* of the body, to a certain proportion of the urea, is purely conjectural. It is not even known how far it may be due to changes in nitrogenous or non-nitrogenous matter; it probably depends upon both. Possibly some estimate of its amount might be made, by studying the amount and the source of the phosphates formed in the system. Urea is probably produced by the decomposition of nervous substance, especially of the albuminoid axial fibres, and non-medullated terminal portions of the motor nerves; urea has been found in the muscles of certain Fishes. The phosphates of the juice of muscle, and the phosphorus in the red corpuscles of the blood, may be a source of phosphates in the urine; but the cerebric acid of the gray nervous substance is especially characterized by containing phosphorus, probably unoxidized; and over-activity and disease of the nervous system, are said to increase the amount of phosphates so excreted. The oxidation of phosphorus, or of phosphuretted fat, may be one source of electro-polar nerve-force. In any case, such molecular polarity is ultimately transformed into heat within the body, and affords another example of the economy with which the various forms of vito-physical force engendered in the animal system, are employed within it. The energy of every substance oxidized in the body, into whatever form of force it may be transmuted, is doubtless applied with the least possible loss.

In conclusion, it may be observed, that, although the results of the application of the principles of physical research to the explanation of the physiological phenomena discussed in this Section, are at present incomplete, yet, considering the extreme complexity of the phenomena exhibited by living animals, and the difficulty, even in regard to Man alone, of obtaining correct average numerical data, enough has been determined to render it certain, that all the strictly physical processes within the body, whether chemical, mechanical, thermic, electric, or photic, are performed by modifications of the common force which produces similar phenomena in the inorganic world around us.

There exists, however, in the living animal, as in the living vegetable organism, a special *formative* or *organizing* energy, evolving the perfect animal or plant from the primitive ovum or ovule, developing its various tissues and organs, and conserving these from the commencement to the termination of its individual existence. The influence of this force, moreover, extends from the parent to the offspring, generation after generation. Its relations to the vito-physical and vito-chemical forms of force working in the body, are entirely unknown. Its truly marvellous results are considered in the following Section on Reproduction Development.

REPRODUCTION.

Spontaneous Generation.

The life of individual organism, whether vegetable or animal, is limited, death, at last, ensuing from accident, disease, or natural causes. The maintenance of the species, by the reproduction of new individuals, is accomplished in different modes in different animals.

All animals, so far as is known, even the very lowest, are produced from *parents.* The occurrence of the original generation of an animal, without the intervention of a parent, or the so-called *equivocal* or *spontaneous generation*, is not believed in by the best authorities. All cases of supposed spontaneous generation, cited before the introduction of good microscopes, may be set aside as valueless. The present condition of the question is fully illustrated in the recent controversy between MM. Pouchet and Pasteur. It is admitted by both those observers, that only the lowest Protozoic forms of animal life are concerned in this question, the assertions of Crosse and others, as to the spontaneous development of a complete Annulose animal, being unworthy of serious consideration.

With regard to the Infusoria, however, it is alleged by Pouchet, that, if impure water be boiled, so as to destroy all organic life in it, and then be absolutely excluded from the air; or if air only be admitted which has previously passed through red-hot tubes; or, again, if water be boiled in flasks which are then hermetically sealed—organisms, belonging to the simplest forms of Infusorial life, will make their appearance; and that these will even be followed by the subsequent appearance of higher ciliated Infusoria. It is strongly asserted that, in such experiments, absolute care has been taken to prevent the accidental intrusion of germs, however minute, into the water or air. By Pasteur, on the other hand, it is affirmed that, if sufficient precaution be taken, no manifestation of life occurs in the fluid experimented upon, or at least, so exceptionally, that it may well be attributed to the accidental entrance of floating germs.

The following experiments have been devised by Pasteur, to illustrate this subject. Small flasks of boiled water have been closely fitted at the mouth with tubes, into a bend or bulb of which cotton-wool is introduced; this intercepts floating germs, but yet allows the interchanges proper to gaseous diffusion: in such experiments, no organisms are developed in the water. On the other hand, with the same fluid boiled, and placed in a flask, fitted with a similar tube without the cotton-wool, multitudes of Infusoria are developed. In other experiments, instead of cotton-wool, gun-cotton was employed, and placed so as to intercept the germs in the air; this gun-cotton being afterwards dissolved in ether, ova and germ-forms were collected in the residue, and recognized under the microscope. Moreover, portions of the cotton-wool or gun-cotton charged with the germs, produced, in water or in vegetable infusions, the same kinds of Infusoria as appeared in the liquids unprotected by the gun-cotton.

It would seem, however, that in boiled vegetable infusions, hermetically sealed with a certain quantity of air, also previously heated to a red heat, those singular organisms, named *bacteria*, which are probably vegetable, may, after *several months*, *appear*. (Child.)

The position of the advocates of the doctrine of spontaneous generation is a difficult one. An apparently positive result, in an experiment with hermetically-closed vessels, is attributed by their opponents to want of care in the preparation of the water or the infusion, or to the accidental intrusion of germs. The position of the opponents of the doctrine is also difficult, because they seek only to establish a negative. A sufficient number of *negative* results, obtained by conscientious observers, is all the evidence that can possibly be advanced in such a case. The *onus probandi* is thrown upon the supporters of the doctrine.

The Various Modes of Reproduction.

In the Vegetable Kingdom, two modes of reproduction are observed, viz., the *non-sexual* and the *sexual*. The former presents several varieties, viz., *gemmation*, or the formation of *buds*, as in ordinary plants, or in special cases, of *bulbs* which are detached buds, or *subdivision* or *fission*, as in the microscopic algæ, and perhaps in the lower fungi. The sexual mode is by true *spores* or *seeds*, which require fertilization. The two modes commonly occur in all plants.

The mode of propagation by *buds*, or by *cuttings*, serves to prolong a variety, or a species, merely by multiplying the individual; but the *sexual* mode alone will render permanent an accidental variety, or will perpetuate, for a length of time, a specific form. In the fungi, and in the lower algaceous forms, it seems probable that an *alternate form of generation* may occur, such as will presently be described in the case of certain animals: that is to say, the two forms of reproduction, *sexual* and *non-sexual*, may alternate in different generations; in other words, spores may produce intermediate forms, which, in their turn, may directly reproduce the parent form.

The reproduction of *animals* from parents, also presents the *non-sexual* and the *sexual* modes.

The *non-sexual* mode of reproduction may either consist in a simple cleavage or division called *fission*, or in the formation of *buds*, known as *gemmation* or *budding*. Both these forms occur only in the lower Classes of animals. *Fission*, or *fissiparous reproduction*, consists of a constriction, once or several times repeated, in the soft body of an animal, followed by its complete division into two or more parts, each of which is then developed into an individual as complete, in every respect, as the parent animal. This form of reproduction is noticed as one mode of development in the Infusorial animalcules, the process being sometimes, as in Paramecium, extraordinarily rapid. It also occurs in the formation of the segments in some vermiform intestinal

Entozoa, but not amongst animals higher in the scale. In artificial fission, as performed upon the Hydra, a similar process is imitated. If, for example, a Hydra be cut, lengthwise or transversely, into several parts, each portion will complete itself. Some of the Annelida, or Worms, on being cut across, develop a new head to the lower half, and a new tail to the upper portion, of the divided body.

Gemmation, or *gemmiparous reproduction*, consists in the formation of an offshoot or *bud*, from the body of the parent animal, which either continues to grow in connection with the parent, so that composite animals are produced, as the many-chambered Rhizopods; or aggregates or *colonies* of animals are formed, attached by a common stem, or *stolon*, as in the case of the Vorticellæ, amongst the Infusoria.

This is, also, the ordinary mode of propagation of the Hydra, amongst the Cœlenterata; of the compound coralline Polyps, of the compound Ascidioida, and of Nais, amongst the Annelida. Gemmæ may also, after a time, detach themselves from the parent stem, move away, and develop as independent animals, which may themselves gemmate, and form a new colony, as in the compound Polyps and the compound Tunicata, or become new independent animals, as in the Medusæ. Sponges are thus reproduced by detached bodies, known as *gemmules*, which, at first ciliated and free-moving, afterwards become smooth and fixed, and then grow into a new sponge.

As representing a special form of *internal gemmiparous* reproduction, may perhaps be included those remarkable cases, in which groups of minute cell-like bodies, sometimes named *pseudova*, to distinguish them from *true ova* or *eggs*, are developed somewhere in the interior of the body of the parent animal, and, after a time, undergo successive stages of development, sometimes into forms externally resembling that of the parent animal, though not possessing reproductive organs, but much more commonly into forms not resembling the parent animal. By detachment, protrusion, or rupture of the parent, these new animals then become independent beings. This form of reproduction is observed in the Aphides only, among Insects, and in the Daphnia, among the smaller Crustacea. Light and heat are important agents in determining the occurrence of this process.

The larger reproductive bodies found in the Sponges, and developed as cold weather approaches, called *capsules*, have, by some, been regarded as of the nature of *pseudova*, but they may be *sexual* products. The so-called *germ-cells* of the Hydra, which, towards winter, are sometimes developed in the walls of the gastric cavity in one individual, whilst a *sperm-cell* appears in that of another, though sometimes both kinds of cells are developed in the same Polyp, have likewise been referred to this class of bodies; but their *sexual* character is more probable.

In the *sexual* mode of reproduction, known as *oviparous reproduction*, which is a higher form of propagation, an *ovum*, or *germ-cell*, and a *fertilizing cell*, or *sperm-cell*, are always necessary, and co-operative, in other words, a *female* and a *male* product, according to the distinction of *sex*.

In some animals, as in the Cœlenterata, in certain Scolecida, as in

Trematode Entozoa, in many Gasteropods, and in a few branchiated Annelida, the male and female products are developed in one individual, which is then said to be *monœcious* or *hermaphrodite*. In the Medusæ, and in the Entozoa, the germ-cells are fertilized by the sperm-cells of the same animal; but in the Snails, and other Pulmo-gasteropods, there is an interchange of office, one individual fertilizing the ova of another, and having its own ova fertilized in return.

In the remaining animals reproduced by true ova, viz., the higher Annuloida and the Annulosa, the Molluscoida, Mollusca, and Vertebrata, the reproductive elements are found in separate individuals belonging to opposite sexes. Such animals are named *diœcious*. The ovum is then, in some cases, as in Fishes and Amphibia, fertilized without, but in other cases, as in Reptiles, Birds, and Mammalia, within, the body of the female or ovigerous parent. In this ovum, when fertilized, the embryo is developed, undergoing a series of important changes, which constitute the process of *evolution* or *transformation*.

Some curious examples of the *coexistence in the same individual*, but at different seasons, of a *sexual* with an apparently *nonsexual* mode of reproduction, have been met with, in the lower Classes of animals. This presents us with the various forms of *parthenogenesis*, or *development* by so-called *unfertilized ova*. This mode of reproduction is illustrated in the Aphis, amongst Insects, in the female of which, one act of fertilization is sufficient for a long succession of distinct reproductive acts. Another most striking example is exhibited by the Bee, as was first observed by Dzierson, and afterwards by Siebold, Berlebach, Leuckart, Owen, and others. The ova of the Queen-bee are deposited by her, in the cells of the comb, and in that act, according to the size and form of the cell, she either fertilizes the ovum, or not. This is accomplished by her permitting, or preventing, the escape of a small quantity of fluid from a sac in the interior of her body, named the *spermotheca*, which has been previously charged, by the act of the male bee, with fertilizing fluid, during flight in the air. If the ovum be fertilized, it produces a working-bee, *i. e.*, an undeveloped female, any one of which, by abundance of feeding, may become a queen-bee. But if the ovum be not fertilized by the fluid of the spermotheca, it produces only a drone, or male. This latter result may be brought about experimentally, either by interruption of the communication between the spermotheca and the oviduct, or by the effects of a temperature low enough to destroy the properties of the fertilizing fluid. So also, if the wings of the queen-bee be cut, she remains with the sac uncharged with the fertilizing fluid, and her eggs, which she will then deposit all the same, produce only drones. Moreover, a working-bee, not fed up to the condition of a queen-bee, may deposit eggs, which, not having been fertilized in the ordinary way, produce only drones. In the Bee, therefore, the phenomenon occurs, of an ovum undergoing development, without obvious direct fertilization. Hence the name *parthenogenesis*. Similar phenomena have now been observed in many other Insects.

In certain remarkable cases, a sexual generation by *true fertilized ova*, or *germ-cells*, may occur, together with reproduction, by apparently *unfertilized pseudova*, or *germinal cells.* This happens, for example, in certain Entozoa, and also in the Aphis, or plant-louse. Sometimes these two modes of reproduction *alternate*, in *different generations*, more or less regularly. In such cases, the form of the animals produced from the *true ova*, or the *first* generation, differs, in some respects, from that of the parent, especially in being nonsexual; whilst the offspring of these, or the *second* generation, derived from *pseudova*, may either resemble the original parents, or may produce, *nonsexually*, a *third* generation, or *several* generations, the last of these producing animals, which are sexual and resemble the parents. This is named propagation by *alternate generation.* In it, a female parent animal produces ova, which are duly fertilized. The embryos, or *larvæ*, developed from these, are, at no time, like the mother; they grow, and then develop, in their interior, either a single individual, which becomes like the parent; or they may, by external division, or external or internal gemmation, produce many such; or they may form, either at once, or in succession, a series of young, derived from unfertilized *pseudova*, which at once, or after two, three, or more generations, ultimately produce animals similar to the first parents. These again, like those parents, propagate sexually. The intermediate generation, or generations, of *nonsexual proliferous larvæ*, have been called by Steenstrup, *nurses*, to distinguish them from *true mothers.*

This development by alternate generation never occurs in the Vertebrata, and only rarely in the higher Non-vertebrata. Amongst the *Mollusca*, no proper example of alternate generation has yet been met with; but it is almost constant in the *Molluscoida.* Amongst the *Arthropodous Annulosa*, it has been observed in but one Crustacean, Daphnia, and in only a few Insects, such as the Aphides, but not in the Arachnida or Myriapoda. The Aphides present a remarkable example of this alternation: in the hot season, they multiply rapidly by successions of internal generations of *pseudova;* but as the temperature is lowered in the autumn, males and females appear, and development by ova ensues. In early spring, these ova again produce viviparous individuals, which multiply by *pseudova*, and, after many generations, towards the approach of winter, sexual Aphides once more appear. This alternate generation likewise occurs in many Annelida, its asexual phase then constituting the so-called *fission*, as in Nemertes, Nais, and others. It is common also, and occurs in all degrees in the Annuloida, as in the Scolecide, the Trematode, and the Cestode parasitic worms, in the Rotifera, and the Echinodermata, and also, generally, in the Cœlenterata, and in many Protozoa. Amongst the Cœlenterata, and others, the form which is evolved from the *fertilized* ovum is named the *scolex;* the compound forms arising from the budding or fission of the scolex are named *strobila*, and the perfect animals, again exhibiting true reproductive organs, are named *proglottides.* In the Sponges, sexual reproductive organs have been seen, giving rise to bodies like ova, in which a spongilla is developed. These alternate with the gemmules. In the unicellular Protozoon, besides fission, the so-called *nucleus* and *nucleolus*, or double nuclei, are believed respectively to represent the *male* and *female* products, not germ- and sperm-cells, but germ- and sperm-nuclei.

This mode of reproduction, by alternate generation, often presents examples of *genetically related* animal forms, exhibiting not only a non-sexual character, but a totally different shape and organization, as compared with the parents. The ovum of certain Echinodermata, of the Echinida and Ophiurida for example, develops into a free-swimming *ciliated embryo*, which becomes converted into a *medusa-like larva*, known as the *pluteus*, a form which has quite a Cœlenterate type; but in the body of this, near the digestive cavity, close upon the remaining substance of the original ovum, or yolk-mass, a *young Echinus* appears in the form of a circular *disc*, which gradually assumes a *quinary radiated* form, and ultimately becomes a perfect Echinoderm. In the same way, the ova of the Tæniæ, or Tape-worms, taken by animals which live upon offal, or swallowed by Man in water, pass into the alimentary canal, and there develop into *Echinococci*, or *Cysticerci*, which penetrate, whilst very minute, the surrounding tissues by a process of boring, and so find their way into all parts of the body, and there grow as Cysticerci or Echinococci. The tissues of the edible animal (as a pig, for example), thus infested, being then eaten, the Echinococci, if not destroyed by the cooking, attach themselves to the intestinal mucous membrane of the person who eats them, and form the *head of a tænia*, which then, by successive fission, produces its long segmented body, each section of which, now named a *proglottis*, is really independent of the rest, and is provided with true reproductive organs, sperm-cells and ova. The Trichina is not, as was once supposed, an intermediate form, by alternate generation.

Lastly, in the interior of certain Trematode worms, such as the Planariæ, and Distomata, a succession of non-sexual larvæ is developed, each producing others within them, until, at last, sexual forms appear resembling the original parent. Thus a Distoma, for example, which is found as an entozoary parasite in the Limnæus, a fresh-water snail, develops ova, which are evolved into elongated larvæ of very simple organization; these larvæ are composed simply of nucleated cells, which grow into ciliated organisms, and then burst through the skin of the larva, attach themselves to a Limnæus, and, having become metamorphosed into a true Distoma, perforate the tissues of the snail.

In these cases of alternate generation, there occurs, therefore, a *sort of metamorphosis*, because the *cycle of evolution* is at last always completed, by a return to the parent form; but the stages of the metamorphosis supervene in *different generations*, and not in the same individual. So likewise, in all cases of *non-sexual* reproduction, whether by so-called fission, by gemmation, external or internal, or by recognized pseudova, a return, at last, takes place to sexual development, by true ova which require fertilization. Hence the latter mode of reproduction appears the more important function, to which is assigned the continuance of the *specific forms* of animal life.

In the Molluscoid Tunicata, however, and in Insects, Crustacea, and certain Fishes, and also in Amphibia, a true *metamorphosis* occurs in each single individual—*i. e.*, a transformation takes place not in the embryo *in ovo* but after the escape of the young from the ovum as an independent being. In such instances, the young animal, on emerging from a fertilized ovum, has at first no resemblance to the parent, but exhibits a provisional form and organization, suited to its conditions of life. After a time, however, it undergoes changes; some organs or parts disappear, whilst others begin to be formed, and, finally, it assumes a state of mature existence, resembling its parent, and exhibiting one or other form of sex. Thus the *larva*, or worm-like *caterpillar*, of the Insect, proceeds from the *egg*. Consuming large quantities of food, it grows, and then changes into the *pupa*, or *chrysalis;* in this condition, no food being taken, remarkable changes occur, of which the formation of wings is the most obvious. From this, finally, it emerges as the *imago* or *perfect* insect. The relative degree or extent of the metamorphosis, differs in different Orders and Families of Insects. The suspension or arrest of the ordinary phases of this metamorphosis, occasionally gives rise to monstrosities, such as butterflies with caterpillars' heads, and other curious forms.

Metamorphosis may also be said to occur in some of the lowest Fishes, certain forms of Ammocete having been shown to be the larvæ of the lamprey, which afterwards undergo comparatively slight changes in the buccal and branchial apparatus.

In the Amphibia, the tadpoles of the frogs and others, as developed from the egg, present a fish-like form, and possess at first external and then internal gills; but ultimately, in the higher forms, they assume the perfect Batrachian conformation, lose their gills, and breathe by lungs. The extent of change is most marked in the anourous or tailless Amphibia. In the salamanders, however, no internal gills are developed, like those of the frog; and the tail, instead of undergoing interstitial absorption, is retained. The suspension of the metamorphic process, at certain early stages, leads to the formation of the Perennibranchiate Amphibia, in which lungs also exist, such as the Proteus, Siren, Axolotl, and Menobranchus.

The preceding cases are instances of *progressive* metamorphosis. But metamorphosis may be, as far as general organization is concerned, *retrograde*, animals being, in the larval stage, actively locomotive, and, in the perfect stage, fixed or sessile. Thus, the young of the Ascidioida are free-swimming, tailed, and ciliated animals, whilst in their perfect condition they are fixed. In the Crustacea, the larvæ exhibit progressive metamorphoses of a remarkable character. In the Cirrhopods, the larvæ are active, move freely in the water, and possess eyes, but, afterwards, they become sessile, fixed by the head, and lose those organs. They present an example of retrograde or recurrent metamorphosis. In the parasitical Crustacean Lerneada, which attach themselves to fishes, and even in the Lamellibranchiate Mollusca, the perfect animal is less highly endowed than when in its larval condition.

The phenomena of *individual metamorphosis*, so obvious in the Insects and the Amphibia, after their escape from the egg, are in reality, not singular; for *phases* of *evolution* or *transformation*, occur in the development of the embryos of all animals, even of the highest Vertebrata; but these are oftentimes *rapid*, and occur in such an early stage of embryonic life, as not to be so obvious.

Ova and Pseudova.—A *true ovum*, the product of a female organ or *ovary*, is a *nucleated cell*, possessing a delicate cell wall, a contained nucleus, within which is a nucleolus, and, besides that, certain cell contents. It is a proper and special *germ-cell*, set apart for the reproduction of a new individual.

The male product, or fertilizing element, the product of the so-called *sperm-cells*, formed in the testes, is a fluid containing microscopic bodies named *spermatozoa;* these are endowed with the power of active movement, which lasts, in the Warm-blooded Vertebrata, for a few minutes, in the Cold-blooded Fishes, for days, and in certain Mollusca and Annulosa, even for months, when received into the special receptacle, or *spermotheca.* From their mode of development, from the character of their movements, and from the effects of reagents upon them, they may be regarded as ciliated gymnoplasts, or ciliated nuclei, which may be compared to single particles of ciliated epithelium. The sperm-cell in which they have their origin, and from which they escape by rupture of the cell-wall, is the homologue of the germ-cell, or ovum.

In *true sexual* reproduction, the product of the sperm-cell enters and fertilizes the germ-cell, and imparts to it the power of specific reproduction, just as the pollen of the anther of a flowering plant fertilizes the vegetable ovule.

The *unfertilized ovum* of a queen or female bee, and also the *pseudova* of the Aphis, and of other animals propagated by alternate generation, are also *nucleated cells*, portions of the parent animal, set apart for particular purposes, and retaining special powers of further evolution; they are, therefore, also *germ-cells*, or rather *germinal cells.* They may be viewed as undeveloped, or ametamorphosed portions of a previously fertilized blastema, which has itself resulted from the first stages of evolution of a true ovum; they are, however, retained in connection with some portion, usually internal, of the non-sexual and only indirectly fertilized offspring, waiting for their opportunity of individual evolution. They have, in truth, *been* fertilized. According to this view, every individual animal form, whether the result of direct sexual evolution, or of parthenogenesis, or of any stage of alternate generation, is produced from a primitive cell, which, having been directly or indirectly fertilized, undergoes multiplication and differentiation, so as to evolve the future animal. The simplest forms of reproduction, by gemmation or by cleavage, are but extensions of individual animals, themselves traceable to the evolution of two primitive, sexually developed, fertilizing, and fertilized cells. Even in the lowest Protozoa, evolutions of new beings, from time to time, occur by the conjugation of two nuclear particles in their interior, which, at least, imitate a sexual process.

Whatever variety the reproductive process of animals may present, the primitive cell, whether it be a *fertilized ovum*, an *unfertilized ovum*, a *pseudovum*, or the commencement of a *bud*, is, in all known cases, a part or product of a *pre-existing parent.* No satisfactory proof has yet been adduced, of the *spontaneous* origin of such a cell. Hence, the doctrine of spontaneous generation collapses from failure of proof.

The Ovum considered generally.

The parts seen in an *unfertilized animal ovum*, as already stated, are the cell-wall, the contents, the nucleus, and the contained nucleolus, Fig. 116. The delicate *cell-wall* constitutes the *vitelline membrane*, or *yolk-sac.* The more or less transparent, granular, or colored *contents*, constitute the *yolk.* The *nucleus* is a transparent, solid, or vesicular body, here named the *germinal vesicle*, or *vesicle of Purkinje.* Lastly, the *nucleolus* within it, is a fine granular or vesicular corpuscle, called the *germinal spot.* The germinal vesicle and spot are the essential parts, or active centres of growth of the ovum.

As to the Vegetable Kingdom, in the higher plants, which are produced from seeds, a part exists in the seed, known as the *ovule;* within this, which is a vegetable cell, is found the *germ-vesicle*, a structure homologous with the germinal vesicle of the animal ovum. Like it, its future development requires the co-operation of a fertilizing agent, which is here derived from the *pollen-cells.* In the lower or flowerless plants, the spores are usually fertilized by *movable filaments* named *zoosperms*, or by simpler elements.

The *size* of the ovum of different animals differs very much, not in accordance with the size of the parent animal, but rather with the course and conditions of development of the future embryo. The difference in size depends almost entirely upon the quantity of the yolk or cell-contents. The character of this yolk also varies: sometimes it is so finely granular and colorless as to appear clear; whilst, in other cases, it is so distinctly granular and colored, as to contain large granules and even vesicles, with oil-globules, to be more or less opaque, and to present a pale or deep yellowish hue.

The *yolk* is a most important constituent of the ovum. In all cases it is *formative*, yielding material for the first formation of the embryo; sometimes it is also *nutritive*, or provides nourishment for it during a considerable period of its growth.

In one series of animals, *oviparous*, the development of the embryo within the ovum occurs entirely after the latter has been deposited by the parent animal; whereas, in another series, often *viviparous*, the embryo is more or less developed within the parent. In the *first case* nutrient material must be specially provided in the ovum for the future embryo, the various organs of which are developed at the expense of the yolk-contents, until the young animal has reached a phase of development in which it can take external materials for its future nourishment. In such cases the yolk is comparatively large in quantity, and rich in organic granular contents, opaque, and colored; it is chiefly *nutritive*, and, in a small part only, *formative.* Such ova are named *meroblastic* (*μέρος*, a part, *βλαστός*, a germ); they include the eggs of the higher Crustacea and Arachnida, those of the Cephalopods, and those of the Osseous and Plagiostomatous Fishes, of Reptiles and

Birds, and of the Monotrematous order of the Mammalia. The ova of the Amphibia are imperfectly meroblastic. In the *second* case, either a very slight part, or no portion, of the yolk is nutritive, but all, or almost all, is directly formative; the yolk is comparatively small, frequently clear, and less rich in granular organic contents. These ova are called *holoblastic* (ὅλος, the whole). They are met with in the eggs of the Echinodermata and of the Annelids, in those of the simplest Crustacea and Arachnida, in those of Insects, and of the Mollusca generally (excepting the Cephalopods), in the Cyclostomatous Fishes, and, lastly, in the Mammalia, including Man.

The *holoblastic* ovum (Fig. 116) consists of a transparent, homogeneous, or structureless vitelline membrane, which, together with a clear outer stratum of the yolk, sometimes of considerable proportionate thickness, constitutes the *zona pellucida*. Within this, and completely filling it, is the limpid, or faintly granular germ-yolk, or formative yolk, with its germinal vesicle and spot. The *meroblastic* ovum (Fig. 119) consists externally of the vitelline or vitellary membrane, which is thin, and often also homogeneous or structureless, but, in some cases, slightly granular, or, in parts, indistinctly fibrous. There is no *zona pellucida*, but the interior of the vitelline membrane is lined with a stratum of polygonal nucleated cells, known as the *epithelial layer*. Within this is the distinctly granular, nutritive yolk, *a*, which may either be whitish or yellowish. On one part of the surface of the nutritive yolk is a small circular disc, known as the *cicatricula* or *germinal disc*. This is in fact the *germ-yolk*, or *formative yolk*, spread out, in the meroblastic ovum, upon a small part of the surface of the nutritive or *food-yolk*, instead of being spherical, and occupying the entire

Fig. 116.

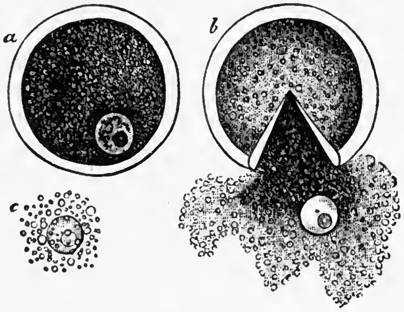

Fig. 116. Holoblastic ovum or germ-cell of a Mammalian animal, unfertilized. (Allen Thomson.) *a*, vitelline membrane or envelope, thick, and clear, afterwards forming the *zona pellucida*; within it is the granular yolk or cell contents; in this, the germinal vesicle or nucleus; and in this, the germinal spot or nucleolus. *b*, the ovum, or germ-cell, burst, part of the granular yolk, with the germinal vesicle and its contained germinal spot having escaped. *c*, the germinal vesicle surrounded by a little granular matter. —Magnified 80 diameters.

vitelline cavity, as in the holoblastic ovum. Lying at one time in the midst of the formative or germ-yolk, or germinal disc, are found, as in the other ova, the germinal vesical and spot (Fig. 117).

In the Mammalia the yolk is so small in quantity as quickly to become insufficient for the nourishment of the embryo, and special structures are very early formed to enable it to derive support from the nutrient fluids of the parent. These are imperfectly developed in the Implacental; but are more complete in the Placental Mammalia. Of the meroblastic ova, those of Reptiles and Birds, but particularly the latter, present by far the most abundant nutritive yolk. From the size of the egg and from the occurrence of all the stages of development during an external incubating process, which may be carried on by artificial means, the egg of the Bird especially presents the most favorable opportunity of watching, from hour to hour, the stages of development of the Vertebrate embryo, within the ovum.

The Ovaries and Ova of the Bird.

The *egg* of the common fowl is first formed within the body of the hen, in the organ named the *ovary*, which is attached to the back of the abdominal cavity, in the lumbar region. In the female embryo of all Birds, two ovaries exist, but almost universally the left one only is present in the mature Bird; the Dorking fowl is an exception, having both ovaries persistent. This is also the case in certain of the birds of prey. The ovary itself consists of a cluster of small spherical bodies, closely invested by membranous *ovisacs*, and named the *ova*. These are at first destitute of the white, and consist only of minute yolks invested with the vitelline membrane. The ovisacs are all held together by a loose areolar stroma and bloodvessels, so as to form a bunch or raceme, and are invested by the peritoneum. To the lower part of the ovary, is attached the wide funnel-shaped opening, or *infundibulum*, of a long tortuous tube, named the *oviduct*, which is also single, being present only on the left side; it opens below into the *cloaca*, or common outlet of the alimentary, urinary, and reproductive organs in the Bird. In the ovary, each yolk is inclosed in its ovisac, the narrow suspensory part of which is named the *pedicle*. The yolks are of all sizes, from that of a pin's head, or smaller, to the completely-formed yolk. In structure, the minute ova at first resemble the holoblastic ovum; but as they grow, they become meroblastic, and the *cicatricula*, or *disc* (Fig. 117) of the *germ-yolk*, or *formative yolk*, is very early recognized upon the rapidly increasing formative yolk; it is nearly always at that part of the yolk which corresponds with the pedicle of the ovisac. It is now that the *germinal vesicle*, c, *g*, with its contained spot, or *macula germinativa* of Purkinje, are distinctly seen; but no nucleated cells exist. The vesicle and spot disappear as the yolk descends along the oviduct, whether the egg be fertilized or not; they are not found when the egg is laid, Fig. 118, but the cicatricula has then become subdivided into two layers, the deeper one containing nucleated cells, many of which are also seen in the central parts of the yolk. As each yolk enlarges, its ovisac increases in vascularity, and, when the yolk approaches maturity, a non-vascular band, or *zone*, forms around it, in which, at a part named the *stigma*, a rupture occurs, and the yolk escapes into the infundibulum of the oviduct. The remainder of the ruptured ovisac, with its coverings, is cup-shaped, and forms the *calyx*, which gradually shrinks, appearing for a time as a cup-shaped body. As the yolk descends along the oviduct, the mucous membrane of this canal, which is vascular and glandular, secretes the *albumen*, or *white;* this is now added to the surface of the yolk, being deposited in spirally-arranged layers, owing to the rotation of the ovum during its descent, in which it is guided by numerous spiral folds of the mucous membrane. The first or inner layers of the white are the densest, and at each end

Fig. 117.

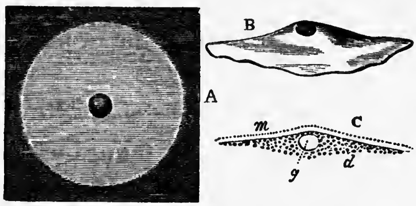

Fig. 117. Part of the yolk of the hen's egg, supposed to be taken from the ovarium (Allen Thomson). A, portion of the surface of the yolk, showing the cicatricula, vitelline disc, or germ-yolk, with the germinal vesicle still present in its centre. (Magnified 6 diameters.) B. side view of cicatricula. C, vertical sectional plan of cicatricula; *m*, vitelline membrane; *d*, granular substance of disc; *g*, germinal vesicle.

or pole, are denser and semi-opaque twisted portions of the white, named the *chalazæ;* the turns of these are in opposite directions, and are also produced by the spiral movements of the yolk in its descent.

Fig. 118.

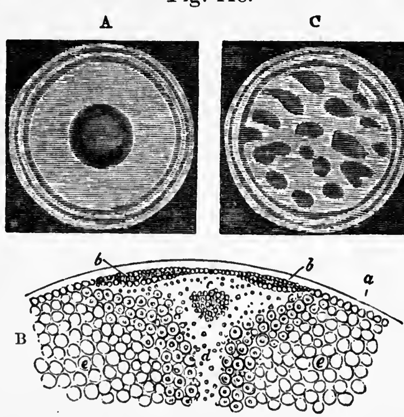

Fig. 118. Cicatricula of the hen's egg, after it has been laid. (Allen Thomson.) *A*, cicatricula, or germ-yolk in a fertilized egg; it shows a transparent central area, looking dark, and a few halones or haloes near the circumference. *B*, vertical sectional plan of the cicatricula and adjacent part of yolk, in a fertilized laid egg; *a*, vitelline membrane; *b*, *b*, thick part of cicatricula or germ-yolk, with thin part or area in the centre; c. group of granules, occupying the position of the former germinal vesicle, which has disappeared in the progress of evolution; *d*, the canal containing white yolk, leading to the latebra; *e e*, the yellow, or nutritive yolk. *C*, cicatricula of an unfertilized egg; it has no germinal vesicle, and no transparent area, but only irregular blotches.

Towards the lower part of the oviduct, the egg, now composed of the yolk and white, enters a dilated portion, known as the *isthmus* of the oviduct, which is lined by a thick mucous membrane, provided with innumerable villi; it is here that the egg acquires a covering which corresponds with the *chorion* of the Mammalian ovum, and becomes partly calcified to form the shell. The inner part forms the *shell-membrane*, and the outer part, becoming calcified, is the *shell*. These being secreted and deposited outside the white, the egg is completed, and then passes through the cloaca to be deposited. Birds are called *oviparous* animals.

The *shell* of the perfect egg (Fig. 119, *e*), is composed of 96 parts of carbonate of lime, 2 of phosphate of lime, and 2 of animal matter. The earthy matter is deposited in minute crystalline particles, embedded in a delicate animal basis; the shell is porous, admitting the evaporation of fluid from within, and the passage of gaseous matters in both directions. The *shell-membrane*, *d*, next within the shell, has the appearance of tissue-paper, and consists of several layers of fine matted fibres, running spirally, and composed, it is said, of solidified

Fig. 119.

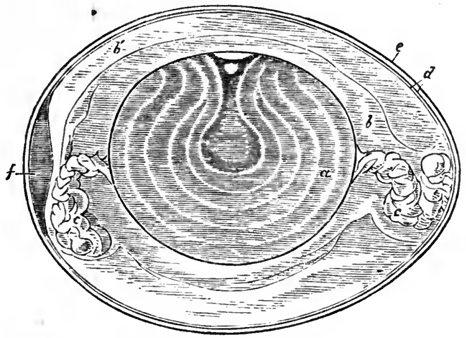

Fig. 119. Section of the hen's egg. (Allen Thomson.) *a*, meroblastic yolk, inclosed by the vitelline membrane. *b*, inner dense part of albumen. *b'*, outer thinner or more fluid part. *c*, *c*, the chalazæ. *d*, double shell membrane. *e*, the shell. *f*, the air-space between the two layers of the shell-membrane. The section of the yolk shows the halones, or concentric layers, also the central cavity or latebra, and the canal leading up from this to the cicatricula or disc at its summit.

albumen. At the larger end of the egg, the shell-membrane separates, after a time, into two layers, between which, from the wasting of the fluid of the egg, air finds its way from without through the shell; the interval is named the *air-space*, *f*; it increases with the length of time that the egg is kept; it is not essential to, though it may assist in, the respiration of the embryo-chick. The *albumen*, or *white* of the egg, is more fluid next to the shell-membrane, but becomes denser in its deeper parts, next to the yolk; it consists of 11.5 per cent. of albumen, 1 to 2 of fat, .5 of saline matters, chiefly chloride of sodium, 2 of extractives, and about 84 per cent. of water. Within the white, the large yolk is held in its place, or moored, by the two coiled elastic threads, named the *chalazæ*, *c*, *c*, and, being lighter than the white, floats in it. Moreover, owing to the chalazæ being attached below the centre, or horizontal axis, of the yolk, a particular portion of the surface of the latter is always uppermost when the egg is laid upon its side; during incubation, therefore, it is next to the hen's body, and more accessible to air and light. The *yolk*, *a*, inclosed within its proper *vitelline*, or *vitellary membrane*, is of a pale-yellow color, and even of a lighter specific gravity than water; it is composed of 29 per cent. of fatty or oily matter, 17 of albumen, traces of phosphorized fatty matter, of cerebric acid, and of salts, amounting in all to 2 per cent., and of 52 per cent. of water. It presents a fluid basis, composed of albumen in solution, mixed with fine granules; in this are contained larger granules, and also larger bodies, called *yolk-vesicles*. These latter are *not true cells*, for they contain no nuclei; they vary from $\frac{1}{400}$th to $\frac{1}{600}$th of an inch in diameter, and are composed chiefly of fat particles aggregated together, but having no distinct cell-membrane or envelope around them, though they may be covered by an indistinct film of firmer albuminous substance. The outer parts of the yolk, as may be seen when it is boiled, are laminated or stratified, the several concentric layers being called *halones* or *haloes*, Fig. 119; in its centre is a cavity, known as the *central cavity* or *latebra*, Fig. 119, in which the yolk is more fluid and contains *true nucleated cells*, mixed with free oil-globules of different sizes, floating in an albuminous fluid, and forming what is called the *white yolk*. This is an extension of the *germ-yolk*. Leading from this central cavity to that surface of the yolk which always floats uppermost, is a *channel*, also filled with white yolk. At the upper end of this channel is the pale, circular spot, or *disc*, known as the *cicatricula* or *germinal disc*, Figs. 116, 117. This, which is the essential part of the germ-yolk, consists, even before the commencement of incubation, of two distinctly separable layers: the upper layer consists of firm and clear substance; the under layer, which is larger, is more opaque, and is composed of *nucleated cells*.

The Mammalian Ovaries and Ovum.

In the Mammalia, the organs in which the ova are formed, the so-called *ovaries*, are always double, one on each side. They are solid and not racemose, as in the Bird, and are of small proportionate size, corresponding with the smaller size of the *holoblastic* ova. They consist of a firm, indistinctly fibrous, vascular stroma, containing numerous vesicles, distended with a clear fluid, and named the *Graafian vesicles* or *follicles*, homologous with the *ovisacs* of Birds. These vary in size, from that of a pin's head to that of a pea, according to the stage of their maturity. The walls of each Graafian vesicle, consist of an inclosing vascular *stroma*, within which is a *membrana propria*, and, within that an *epithelial* layer or layers, forming the *membrana granulosa*. Embedded in a part of this latter, named the *proligerous disc*, is the minute holoblastic ovum, averaging about $\frac{1}{100}$th of an inch in diameter. The size of the Human ovum varies from $\frac{1}{240}$th to $\frac{1}{120}$th of an inch, that of the germinal vesicle, from $\frac{1}{760}$th to $\frac{1}{2000}$th of an inch in diameter. In the Mammalian ovary, the ovisac, or wall of the Graafian vesicle, is not everywhere in close contact with the ovum, as in Birds.

At a certain period, a Graafian follicle bursts, not by a fissure, but by a small opening, and the ovum, with some of the nucleated cells of the membrana granulosa, a few of which have now acquired a club-shape and cling to the ovum in stellate masses, enters the funnel-shaped end of the so-called *Fallopian tube*, which corresponds with the oviduct in the Bird. Down this tube the ovum descends by peristaltic action, perhaps aided by the movements of cilia, into the cavity of the *uterus* or womb, within which it undergoes its future development. Each ovary has its own Fallopian tube.

The emptied Graafian follicle, the walls of which have previously become thickened and vascular, is first filled with effused blood, which becomes absorbed. A yellow substance is then deposited in its coats, and, becoming plicated, forms the so-called *corpus luteum;* this is vascular, and consists of cells arranged in a columnar manner, mixed with soft fibres and a yellowish fat. It gradually disappears.

In the meantime, the lining membrane of the uterus, with its columnar ciliated epithelium, has become thickened and more vascular, and certain glands within it are highly developed, so as to form perpendicular tubuli. The intertubular substance also undergoes hypertrophy, soon containing many new cells, with much fluid and fatty matter, thus forming a soft nutrient matrix, from which, by mere imbibition, the early ovum may be nourished. The *superficial* stratum of the altered mucous membrane, thus modified, becomes changed into the soft, pulpy, opaque membrane, known as the *decidua*, because it is thrown off with the embryo at birth. This membrane consists, after a time, of two layers, known as the *decidua vera*, and the *decidua reflexa.* The decidua vera is cribriform, being perforated by little orifices corresponding with the enlarged uterine glands; it lines the uterus, but is wanting at the orifice, and also at the openings of the two Fallopian tubes. It contains tortuous arteries proceeding from the uterus, together with large veins and venous sinuses, fine areolar tissue, nucleated cells, and soft granular matter. As this structure grows, it ultimately forms the *maternal portion* of the *placenta*, with its arteries, and venous *sinuses* or *lacunæ*, which is intended to convey nourishment to the future embryo, and to accomplish the respiratory changes in its blood. To some part of the decidua vera the ovum soon becomes adherent, whilst the *decidua reflexa*, as its name implies, covers in the ovum, either owing to a sinking-in of that little body, or to a rising-up of the decidual membrane. Ultimately the two portions of the decidua coalesce, or the reflected part disappears. At the same time that the decidua generally is becoming converted into the maternal portion of the placenta, the ovum itself, having been fertilized, grows rapidly, and undergoes remarkable changes in its interior—some relating to the formation of the embryo itself, others referring to the coats or membranes which constitute its means of protection and of attachment to the maternal placenta. The outer vitelline membrane, which, from its thick and transparent albuminoid character, is named the *zona pellucida*, having lost the club-shaped adherent cells of the membrana granulosa, has developed around it a thin, but strong whitish membrane, named the *chorion*, corresponding with the shell-membrane of the Bird's egg. The chorion is a fibrous membrane, having a layer of tessellated cells outside it. At first, smooth on its outer surface, it speedily becomes covered over with minute, soft, scattered knobs, which soon enlarge and form simple villi. These, composed of nucleated cells only, like the outer tessellated layer of the chorion itself, grow rapidly, and form swollen or club-shaped ends, which embed themselves in the soft structure of the early decidua vera, from which they doubtless actively absorb nourishment for the ovum. Afterwards, these primitive villi are replaced by other branched or tufted villi, which form the so-called *shaggy* or *villous chorion*. These latter villi, after the others have disappeared, continue to enlarge, receive blood-vessels proceeding from the embryo now forming within the ovum, and so produce *vascular processes* or *tufts*, which project, or depend, into the venous sinuses or lacunæ of the maternal portion of the placenta. They constitute the *embryonal* or *fœtal portion* of the placenta, and, coming into close relation with the maternal blood, are the organs by which the nutrition and respiration of the embryo are henceforth carried on.

The chorion itself soon becomes lined with another membrane, named the *amnion*, which, as will afterwards be described, is derived from the embryo, and contains a fluid, the *liquor amnii*, which serves to protect the fœtus *in utero*, until the moment of its birth. The Mammalia are called *viviparous* animals.

The Ovaries and Ova of other Animals.

The description of the ovum of Mammalia and Birds applies, in most respects, to the ova of the other Vertebrata; but there are certain peculiarities in some of these, and in the ovaries in which they are formed. The same parts in the Non-vertebrate animals, also require notice.

Reptilia.—In the Reptiles, which like Birds are oviparous, the ovary is also, as in them, racemose, and, as a rule, single. The yolk is large, and covered with an abundant white, inclosed in a shell; but this is soft, instead of being firmly calcified. When the yolk is formed, the ova escape, by dehiscence, into the abdominal cavity, and are afterwards received into the oviduct, which is placed at a considerable distance higher up. By these, as in Birds, they are discharged into the cloaca, and thence are generally deposited externally, or oviparously. In the viper, the slow-worm, and green lizard, however, the development of the embryo takes place partially within the body of the parent; hence such reptiles are said to be *ovoviviparous.*

Amphibia.—In the Amphibia, the ovaries are double, and the ova are no longer, as in the Mammalia, Birds, and Reptiles, brought to maturity in *succession*, but *simultaneously;* being received into the oviducts, they are conveyed to the cloaca, and are then deposited in the water, either singly, in chains, or in masses. They are surrounded by a soft, mucous, areolar tissue, which swells up in the water, keeps the ova apart, allows light and aerated water to get between them, and supplies temporary food to the young tadpoles.

Fishes.—In Fishes, the ovaries are also double and symmetrical, and are chiefly remarkable for the enormous number of ova developed in them. The number of ova in a codfish has been found to be upwards of 3,500,000, in a flounder, 1,300,000, and in a mackerel, more than 500,000. They are usually matured and deposited simultaneously, but in the case of migratory sea-fishes, like the herring, probably at successive periods. In certain Fishes which are ovoviviparous, the ova are few in number, and are deposited at short intervals. Most commonly the ovaries have an excretory duct, continuous with them, like the *duct of a gland*, by means of which the ova are discharged into the water. The Cartilaginous, and a small number of Osseous Fishes, however, have no such excretory duct, but the ova pass into the peritoneal cavity, from which they escape, in the Cyclostomata, by an orifice on the under side of the hinder part of that cavity, named the *abdominal pore*. In the sharks, a short tube, or rudimentary oviduct, first receives the ovum. In a sort of chamber, connected with this, the peculiarly-shaped, horny, protective case is secreted, like a chorion, in which the ovum is discharged.

In the Non-vertebrated animals the ovaries are neither solid and parenchymatous as in Mammalia, nor racemose as in Birds, Reptiles, Amphibia, and Fishes. In the higher forms they consist of *sacs*, *cæca*, or tubuli, which may be simple or ramified, and which, like a gland, have an attached or *connected* duct, named the *oviduct*, which, however, is not separate from the ovary, as in most Vertebrata. In the lowest forms, the ova are developed, sometimes in a loose filamentous tissue, or in membranous plicæ, or upon stalks or processes in the interior of the body, as in the Cœlenterata, or are actually embedded in its substance, as in the Protozoa.

Mollusca and *Molluscoida*.—In the Cephalopods, the ovaries are saccular. The ova are developed upon short processes in these sacs, and, when detached, leave a part behind, somewhat resembling a calyx. They are received into a special chamber, in which a protective covering is superadded to them. In the other Mollusca, the ovaries are found either arranged in strings, or in masses in the body-cavity. In the Lamellibranchiata, the ovaries are follicular. In the Molluscoida, the ova, developed in follicles, are discharged by the oral cavity.

Annulosa and *Annuloida*.—In Insects, the eggs are generally numerous; the ovaries are cæcal, like the follicles of *glands;* they are double and symmetrical, but have a common outlet, in a sort of cloaca; frequently, the eggs are laid by aid of an *ovipositor*. The females of many Insects have a reservoir, known as the spermotheca, like the bee. In the Crustacea, the ovaries are also double, each having its own outlet; they form cæca, usually branched, but in the lower forms, simple. The oviducts are often provided with a spermotheca. The Arachnida have elongated vesicular ovaries. In the Myriapoda, they are like those of Insects. In the Annelids, the ovaries have no oviducts, but the ova are set free in the perivisceral cavity. Amongst the Annuloida, in the vermiform Scolecida, the ovaries are either simple, or, more commonly, consist of much-ramified tubuli. The ova are numerous, and are discharged from a proper outlet, or from the anal orifice. In the Tænia, the ovaries are multiple, like the body; each segment has its ramified canals; in one species, the total number of eggs, in all the segments, is said to be 64,000,000. In the Rotifera, the ovary is single and saccular; the young are sometimes developed, more or less completely, within the parent animal. In the Echinodermata the ovaries are ramified tubes, modified according to the shape of the body of the animal, there being usually a pair in each arm or segment; but in the Holothurida, they are single, have terminal clusters of cæca, and open near the mouth.

Cœlenterata.—In some of these, as in the Physograde and Cirrhigrade forms, the ova are developed in clusters on the base of the cirrhi. In the Pulmograde forms, they are developed in sacs in the body-cavity. In the Actinozoa, they adhere to plicated folds of membrane, in that cavity. There are no oviducts, and the ova are discharged from the oral aperture.

Protozoa.—In these animals, the germ-cells scarcely appear like true ova; they form on, or in, the substance of the parent.

From the preceding account, it is evident that the ovaries are homologous with glands; so that the germ-cells, or ova, may, as well as the sperm-cells, be regarded as the products of a special nutrient secretive act.

The Fertilization of the Ovum.

The fertilization of the ovum, whether it occur within or without the body of the ovigerous parent, requires the contact of the male fertilizing agent, which, in many cases, has been recognized under the microscope, by the actual presence of *spermatozoa* upon, or even within, the zona pellucida of the Mammalian ova, or upon, or within, the vitelline membrane in other ova.

In the Mammalia, fertilization occurs in the Fallopian tube, or in the uterus. In Birds and Reptiles, and in the higher Cartilaginous and a few Osseous Fishes, which are ovoviviparous, it takes place as the yolk enters the oviduct, before it receives its coating of albumen. In Amphibia, it happens at the time of deposit of the ova, and in Fishes, with the exception of a few, immediately after. In the Mollusca and Molluscoida, Annulosa and Annuloida, and Cœlenterata, fertilization occurs within the body, whether the sexes be distinct, or

Fig. 120.

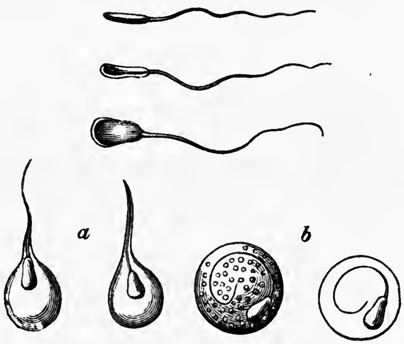

Fig. 120. *a*, spermatozoa of the squirrel. *b*, spermatozoa of the dog, still inclosed in the sperm-cells. Three spermatozoa are shown free, above. Very highly magnified. (Wagner, Leuckhardt.)

whether hermaphrodite individuals contain both ovaries and fertilizing organs. Even in the Protozoa, separate nuclear bodies exist, which combine or conjugate, previously to the reproduction of new individuals.

In the Mammalian ovum, it is said that the germinal vesicle approaches one side of the germ-cell, and even has its germinal spot turned in the same direction—that is, towards the side directed to the place of rupture in the Graafian follicle. Such a movement would certainly facilitate the access of the fertilizing agent to the germinal vesicle and spot, that is, to the nucleus and nucleolus of this primitive cell.

In the Frog's spawn, the spermatozoa have been seen in the jelly-like envelopes of the ova, and also within the ovum. In certain Osseous Fishes, a minute, funnel-shaped aperture, named the *micropyle*, forms, at one period, in the vitelline membrane, and admits the entrance of the spermatozoa. A micropyle has also been seen in the ova of the Lamellibranchiate Mollusca, of certain Insects, and of some Echinodermata. In these cases, the vitelline membrane is relatively thick. No micropyle has been seen in any of the Vertebrata, excepting in Osseous Fishes.

DEVELOPMENT.

CHANGES IN THE OVUM. FIRST FORMATION OF THE EMBRYO AND ITS APPENDAGES.

The first essential change which occurs in the fertilized ovum, is the so-called *cleavage* or *segmentation* of the yolk. In the *holoblastic* Mammalian ovum, the yolk is seen to be agitated by a peculiar movement—to elongate, contract itself in the middle, and then to divide into two. Each half rapidly undergoes further movement, contraction, and division, so that it now consists of four parts. By subsequent subdivision, these next form eight, sixteen, thirty-two parts,

Fig. 121.

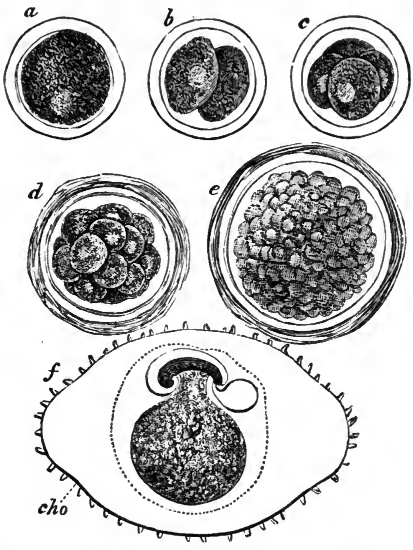

Fig. 121. Changes in the ovum of a Mammalian animal, after fertilization (Allen Thomson). *a* to *e*, successive stages in the segmentation or cleavage of the yolk. *a*, yolk still undivided; *b*, cleft into two masses, each surrounding a nucleus: *c*, divided into four; *d*, non-divided; *e*, mulberry-like stage of subdivision, to form the blastoderm. The small nucleated yolk-masses have no distinct envelopes. The ovum has acquired a thicker coat, or chorion. After this, the surface of the yolk again becomes smooth, and composed of nucleated cells, having true envelopes. The diagram *f*, shows the relations of the embryo and its so-called appendages. The dark curved body is the *embryo*; beneath it is the open part, leading by the *vitelline duct*, to the *yolk-sac*, or future *umbilical vesicle*. Immediately surrounding the embryo, above it, and at each end, is the sac of the amnion, or true *amnion*; the dotted line shows the false amnion. Outside this, is the *chorion*, *cho*, with its rudimentary *villi*. The bladder-like organ, projecting from the hinder end of the embryo, is the *allantois*.

and so forth. The first effect of this cleavage, is to transform the yolk into a mulberry-looking mass; but, after repeated subdivision, the surface again becomes smooth, and uniform or granular, and is composed entirely of an immense number of polyhedral nucleated cells, which form a layer within the vitelline membrane, and constitute the so-called *germ-sac* of Coste, or *blastodermic vesicle* of Bischoff. The central fluid part becomes clear. The segmentation of the entire yolk, has been observed in all cases of development from *holoblastic* ova, even in Non-vertebrate animals. In the eggs of certain Branchio-gasteropods, a remarkable *revolution* of the yolk takes place, subsequently to the period of its segmentation, the yolk turning first in one way and then in another, within the vitelline membrane; this is said to depend on ciliary movements. In the *meroblastic* ova of the Cephalopods, certain Fishes, Reptiles, and Birds, only a part of the yolk, viz., the *germ-yolk*, in the neighborhood of the germinal vesicle, undergoes this segmentation, the result being the formation of the *germinal disc* or *cicatricula*, already mentioned, from which, however, an extension of a single layer of cells proceeds over the unsegmented portion of the yolk, forming the so-called *germinal sac.*

This yolk-cleavage is a phenomenon of *cell-division.* It is stated by Müller, Gegenbauer, and Leydig, that the germinal vesicle, or nucleus of the cell of the ovum, and the germinal spot, or nucleolus of that cell, are directly concerned in this process. The nucleolus and nucleus are said to divide successively into two, four, and many nuclei; around which the yolk, apparently governed by these successive subdivisions of the nucleus, gathers for the development of the nucleated cells. In the last generation, these cells acquire distinct cell-walls. According to others, in certain animals, the germinal vesicle and germinal spot, the primitive nucleus and nucleolus disappear completely, immediately after fertilization occurs, and their future destiny cannot be traced; but a *fresh cell* or *nucleus* is supposed to be formed, around which the yolk gathers, and by the repeated subdivision of this, into two, four, eight, and so forth, the cleavage of the yolk is accomplished. The first cell from which these arise has been named the *embryo cell.* According to the former view, the cells which appear on the surface of the yolk, and out of a part of which, as we shall immediately see, the embryo itself begins to be evolved, are derived *directly* from a nucleus, once forming a part of the maternal organism. According to the latter view, they, and therefore the embryo, are developed *indirectly*, or independently, after the solution and diffusion of the *primitive* germinal vesicle and spot, with the fertilizing agent, in the substance of the yolk. In the flowering plants, also, the nucleus or germ-vesicle of the ovule, or ovum-cell, is said, by some, not to participate in the formation of the cells from which the embryo plant is developed. Whichever of the preceding views be adopted, the cleavage of the yolk is attributed, however, to the formative force, known as the *germ-force*, resident in the first-formed nucleus and nucleolus, and continued in all their successive subdivisions. The germinal vesicle and spot, as already stated, are said to disappear even in unfertilized Birds' ova.

The formation of the layer of nucleated cells which constitute the *germ-sac* of the holoblastic, or the *germinal disc* of the meroblastic, ovum, as a result of the cleavage of the yolk, is altogether preliminary to the formation of the embryo, which cannot yet be recognized. In the Non-vertebrate *holoblastic* ovum, as, for example, in the Nematoid Ascarides, these cells soon aggregate into a more or less coiled opaque mass, which assumes the shape of the embryo, and then, by further development, actually forms the young animal. This is also the case in the Echinodermata, the smaller Crustacea, and Arachnida, the Insecta, and the Mollusca, except the Cephalopods. But in the higher animals, with holoblastic ova, such as the Cyclostomatous Fishes, the Amphibia, and the Mammalia, the cleavage-cells form, at a certain part of the germ-sac, a small opaque hemispherical mass, which soon spreads out into a *disc-like* layer, and constitutes the so-called *germinal disc* or *area*, *area germinativa*, *embryo-spot*, or *blastoderm*. It is the central part of this which is directly concerned in the formation of the embryo. In the Molluscous, and other animals just enumerated, no such germinal area is found. In all the *meroblastic* ova, whether of Non-vertebrate or Vertebrate type, as is well seen in the hen's egg, the *cicatricula*, or *germinal disc*, already described, constitutes this germinal area or embryo-spot.

In this area, as in that of the higher holoblastic ova, the first traces of the embryo are formed. Amongst the Non-vertebrate types, those of the higher Arachnida, and Crustacea, they appear as a certain number of *opaque spots*, having a beautiful symmetrical arrangement, whilst in the Cephalopods, they commence by a small number of primitive masses. In the Vertebrate holoblastic or meroblastic ova, the commencement of the embryo is always indicated, amongst other things, by the appearance of a *linear primitive streak*. This is quite characteristic of the Vertebrate type of ovum, not occurring even in the elongated Annulose type. The evolution of the Vertebrate embryo can alone occupy our attention here. That of the chick *in ovo* will be generally followed; but the peculiarities of the ovum of the Mammalia will also be indicated.

When first formed, the appearance of the *blastoderm*, or blastodermic layer of the germinal area, is nearly or quite uniform, all its nucleated cells being alike, and the result of a homogeneous evolution. But soon a heterogeneous development ensues, cells of different character, and collected in peculiar situations, appear, and, by more special aggregations, and wider differentiations, the various parts which form the embryo, its organs, tissues, and appendages, are evolved.

First, the germinal area or disc increases in size or thickness, by the formation of new cells; as already mentioned, it very early consists of two layers, named the *upper*, *external*, or *serous*, and the *lower*, *internal*, or *mucous germinal lamina*, or *plate*; between these, a *middle* germinal layer, lamina, or plate, is soon formed, but rather in connection with the serous layer. The internal layer, epithelial in structure, is soon prolonged over the germinal sac, which covers the yolk; the outer layer also extends itself, but the middle layer does not pass beyond the limits of the embryo-spot. As the germinal area enlarges, it presents a central transparent region, known as the *transparent area*, or *area pellucida*, around which is a denser portion, named the *opaque area*, or *area opaca*; beyond this is the *vitelline area*. The transparent area is at first circular, but soon oval, and afterwards pear-shaped; in it, the first rudiments of the embryo appear, in the form of a linear oblong mark, or *streak*, called the *primitive trace*, or *groove*. This consists of a median or *axial* furrow, bounded by two lateral longitudinal plates, named the *laminæ dorsales*, which enlarge and elongate, as the area itself becomes larger and pyriform in outline. Beneath this groove, immediately below its floor, appears a delicate, semi-opaque thread, at first cellular, but soon becoming cartilaginous, named the *chorda dorsalis* or *notochord*, which part, so characteristic of the Vertebrate type, is recognizable in the chick, as early as 18 hours after incubation. These are the rudimentary parts of the embryo, one end giving origin to the head, and the other corresponding with the tail. The position of these rudiments is remarkably constant in the hen's egg, always lying transversely to the long axis of the egg; as the embryo-chick develops, it turns upon its side, so that the forepart of the head usually faces the narrow end of the egg.

In the rudimentary stage just described, a vertical section *across* the embryonal line of the germinal area would show the edges of the three *germinal layers of the blastoderm*, with the primitive groove or furrow in the centre, and the cross-section of the chorda dorsalis beneath it.

From these three layers, the parts of the future embryo are thus evolved. From the upper external or *serous* layer, also named the *sensorial* layer, are developed, along its axial portion, the cerebro-spinal nervous axis, and the organs of the senses; and, from its lateral portions, the cuticle, or outer skin, with its epidermic appendages, the feathers, bill, and claws, and in Mammalia, the nails and hairs; lastly, the sebaceous and sudoriferous cutaneous glands, and the Meibomian, ceruminous, and mammary glands. From the *middle* layer, also called the *motorio-sexual* layer, are developed, by complicated metamorphoses of its substance, the bones, the muscular system, the peripheral spinal nerves, the sympathetic nerves, the heart, bloodvessels, and lymphatic system, the so-called ductless glands, and the reproductive organs; also, next to the external layer, the true skin, and, next to the internal layer, the muscular and submucous coats of the alimentary canal. Lastly, from the *internal* layer, also called the *mucous* or *intestinal* layer, are developed the epithelial lining of the alimentary canal, and all its glandular extensions, such as the mucous, gastric, and intestinal glands, the pancreas and the liver, also the lungs and respiratory passages, and the urinary apparatus, including the bladder, ureters, and kidneys.

Whilst, therefore, the middle layer gives rise, by very striking differentiations, to a great variety of tissues, the upper and lower layers, except that part of the former which gives origin to the brain and spinal cord, produce textures composed of simpler forms of cell-tissue.

These layers also contribute, in a manner to be presently described, to the formation of three parts or *appendages* external to the body of the embryo—viz., the *amnion*, the *yolk-sac*, or *umbilical vesicle*, and the *allantois*.

GENERAL DEVELOPMENT OF THE EMBRYO AND ITS APPENDAGES.

The borders of the primitive or vertebral groove, including parts of the external and middle layer (the former named the *medullary plate*, and the latter the *vertebral plate*), rise up on each side, and ultimately unite along the middle line, to form a *canal*, containing the rudiments of the future brain and spinal cord; the anterior part or cephalic end of this canal becomes more expanded than the rest, whilst the posterior part tapers to a point. In this way, the so-called *neural cavity* (p. 114) of the future animal, is formed *above* the chorda dorsalis, traces of which are, for a time, found passing through the bodies of the growing vertebræ. Soon, from the vertebral plates, where these turn upwards, the external and middle layers extend sideways, constituting the so-called *lateral plates*, which, growing downwards, and bending inwards, form the walls of the abdomen, and inclose a cavity which is placed *beneath* the chorda dorsalis, immediately in contact with the yolk; this ultimately constitutes the *hæmal* or *thoracico-abdominal* cavity of the future animal; it soon contains the heart and great bloodvessels, and the rudiments of the alimentary canal, which is completed by a corresponding folding-in of the internal blastodermic layer, which lies immediately upon the yolk.

The embryo, by the bending in of its sides, next appears to be raised from the yolk, and partially shut off from it, by a sort of constriction which takes place, first beneath the head and the caudal extremity, and afterwards at each side. Ultimately, this constriction shuts off the body of the embryo from the yolk-sac, which then communicates only by a narrow passage, the *ductus vitelli*, or *vitelline duct*, with the central space in the interior of the embryo, now the rudimentary alimentary canal, lying in the hæmal cavity. The yolk-sac thus cut off, shrinks, and forms the *umbilical vesicle*. The head of the embryo, now free, bends down towards the yolk, and forms the *cephalic flexure*. At the same time, a delicate transparent membranous fold, derived from the external germinal layer of the blastoderm, rises, like a hood, over that part of the embryo; a similar, but smaller fold, rises over the free caudal extremity; and on each side, where the lateral plates bend in to form the constriction just described, corresponding folds arise. These folds are double; they grow, and at length meet over the back of the embryo, and coalesce so as to form, by their innermost layer, a complete, but delicate, closed sac, called the *amnion*, which, in the chick, is perfected as early as the third day of incubation. This is at first close to the embryo, but it soon expands, and carries with it the outer layer of the same folds, which afterwards reaches the shell membrane in the Bird, but in the Mammalian ovum becomes attached to the inner surface of the chorion, and so forms the *false amnion*. The sac of the amnion surrounds the vitelline duct, in a sort of sheath, and thence becomes continuous with the skin covering the body of the embryo (see Fig. 121).

The amnion is thin, transparent, and non-vascular. It consists, at first, of a structureless basement-membrane, lined with a delicate squamous epithelium; afterwards, it contains fusiform cells and a fine areolar tissue, and, in Birds, even non-striated muscular fibres. Its fluid contents, the *liquor amnii*, usually alkaline, consist of water, having in solution from 1 to 3 per cent. of solid matter: this is composed of a little albumen, traces of urea and uric acid, allantoin, and other extractives, salts, such as lactate of soda, and sulphate and phosphate of lime, and lastly, sebaceous matter, epidermoid scales, and minute hairs thrown off from the embryo.

The amnion, considered as an appendage of the embryo, is chiefly protective, but may be respiratory or emunctory. It is present not only around the embryo of the Bird, but also around that of Mammalia and Reptiles. The embryos of the Amphibia and the Fish, however, which are developed in and surrounded by water, are destitute of an amnion, no such covering being formed, and no folding over of the external blastodermic layer taking place, as in the ovum of the Reptile, Bird, and Mammal.

The *umbilical vesicle* or *yolk-sac* already mentioned, may also be regarded as another appendage of the embryo. It is formed, as just described, by the lower part of the yolk-sac, surrounded by an extension of the innermost germinal layer, and connected with the intestinal canal of the embryo by the constricted passage named the *vitelline duct* (Fig. 121). It is not only external to the body of the embryo, but also outside the cavity of the amnion. Very early, certain bloodvessels are developed in the middle germinal layer of the embryo, and, spreading into a network of vessels, they extend upon the surface of the yolk, and form the so-called *vascular area.* Two special branches, named the *omphalo-mesenteric arteries*, convey blood from the embryo through this area, and a vascular membrane is thus formed, which gradually covers the umbilical vesicle or yolk-sac, and also extends itself, at least in the Birds' and Reptiles' eggs, by numerous projecting folds, into the substance of the yolk. From the substance of the yolk, these bloodvessels absorb dissolved nutrient material; and, for a time, the blood contained in them, is aerated by interchanges of carbonic acid and oxygen, between it and the other fluids of the egg or ovum. In the Bird, the yolk-sac is very large; it is gradually drawn into the abdomen of the chick, and may be found in that cavity after the chick is hatched. In time, its contents are gradually absorbed, and its remains are frequently traceable as a short blind sac or stem, the *vitelline cœcum*, connected with some part of the small intestine. Similar changes are observed in Reptiles. In the Plagiostomatous Fishes, as in the sharks, the yolk-sac remains, for a long time, suspended to the abdomen of the young fish. In the Osseous Fishes, the yolk being smaller, soon disappears. In the Cyclostomatous Fishes, and in the Amphibia which have holoblastic ova, the yolk-sac is still smaller and more transitory. Lastly, in the Mammalia, it is very minute, but undergoes slight growth, especially in the Carnivora and Rodentia. It is found, after a time, as a circular, pale-yellow disc, attached to the amnion, and having no further function; sometimes, as in Ruminantia, it is completely absorbed.

Besides the amnion and the yolk-sac, another most important appendage of the embryo in Birds, Reptiles, and Mammalia, remains to be described. This is the so-called *allantois.* In the Bird's egg it appears as a small eminence, at first consisting of nucleated cells, but soon becoming vascular, situated on the under side of the embryo close to its caudal end. It is derived from portions of the internal and middle germinal layers, which, in this situation, form the intestinal part of the alimentary canal. The allantois soon becomes a hollow protrusion of the intestinal wall, growing out, in the form of a sac or bladder, beyond the body of the embryo, and being placed like the umbilical vessel, *outside* the sac of the amnion (Fig. 121). It carries out with it numerous bloodvessels, which are developed in the middle germinal layer, and are connected with the great vascular trunks of the hinder part of the embryo. It quickly extends itself till it reaches the inner surface of the shell-membrane of the egg, over the interior of which it spreads, with its walls closely applied to each other, so as to form a double membrane, the outer layer of which, in contact with the shell-membrane, retains its bloodvessels, whilst those of the inner layer next to the white of the egg become shrunken. The hollow stalk or stem of the allantois, which is situated within the embryo, opens into a small cavity, developed in connection with the lower end of the intestine, named the *urogenital sinus*, which forms the rudimentary *urinary bladder*. Between this cavity and the opening in the walls of the embryo, through which the vitelline duct passes to the umbilical sac, hence called the *umbilical opening*, the allantoid canal closes, and is converted into the *urachus* or *superior ligament of the bladder*. Outside the umbilical opening, the bloodvessels of the allantois, now named the *umbilical vessels*, ramify in the outer layer of the allantois, next to the shell-membrane, forming a densely vascular structure applied to the inner surface of the whole shell, separated from it only by the shell-membrane. In an early stage of development the allantois of the Bird is contractile, and acts as a sort of urinary bladder, its fluid containing urea, allantoin, sugar, certain salts corresponding with those of the blood, with slight traces of albumen. It receives, indeed, the secretions of certain organs known as the *Wolffian bodies*, or *primordial kidneys*, and also those of the rudimentary kidneys themselves. Its superficial vascular layer next to the shell-membrane, which has been named the *endochorion*, is the active respiratory organ of the embryo bird, after the vessels upon the yolk-sac have ceased to be sufficient for this purpose. The blood to be aerated passes from the embryo through the umbilical arteries on to the allantois, and returns to the embryo by the umbilical vein. As the period of hatching approaches, the vessels of the allantois and this membrane itself become partially dried; the young bird chips the egg, and begins to breathe by its lungs. By the time it escapes from the shell, the allantois and its vessels are quite desiccated.

The allantois is present also in Reptiles, the shell of the eggs of which is soft and thin, and the oxygenation of the blood easily performed. In Amphibia and Fishes there is no allantois, the respiration of their embryos, which are entirely aquatic, being at once accomplished by means of gills, so that no allantois is needed.

In the Mammalia, however, the allantois is invariably present, and fulfils a most important office; for it is the means of conveying outwards from the embryo to the maternal structures the vessels which connect the two and serve in the functions of nutrition and respiration. Its inner part forms, as usual, the urachus, and joins the apex of the future urinary bladder; and its outer part for a time constitutes the so-called *allantoid sac.* This outer part extends itself till it reaches the inner surface of the chorion. As already described, this last-named structure is formed upon the altered vitelline membrane, and soon becomes covered on its outer surface with little knobs; these are developed into temporary villous processes, composed entirely of nucleated cells, and employed in absorbing nourishment for the early mammalian embryo. After a time these simple villi disappear, being, as it were, obliterated by the growth and distension of the chorion. But then, the chorion itself, and the *outer layer* of the amnion, or *false amnion*, which is now in close relation with the chorion, becomes the seat of development of other processes, which, with a thin covering of cells from the chorion itself, form the ramified tufted villi of the so-called *shaggy chorion.* As the allantoid sac of the Mammalia, with its contained bloodvessels, grows, it reaches the inner surface of the chorion, and its vessels entering the villous processes of the latter, form loops in their interior. These processes, now vascular, and constituting the *embryonal* or *fœtal portion* of the placenta, penetrate through the decidua into the *maternal portion* of the *placenta*, projecting into its venous sinuses and lacunæ, and form the so-called *fœtal villi.* These are covered by their own epithelium and basement membrane, and also by a loose layer belonging to the lining-membrane of the maternal venous sinuses. The blood of the Mammalian embryo, passing along the umbilical arteries, upon the allantois, circulates through these fœtal villi, which are themselves bathed with the maternal blood. The two bloods come into close relation, being separated only by the most delicate tissues, but they do not intermingle. In this way nutriment is absorbed from the maternal blood, for the maintenance of the growth of the embryo; and possibly effete matters are especially eliminated from the embryonal blood. This latter blood is oxygenated by a respiratory process, consisting of an interchange of carbonic acid and oxygen between the embryonal and maternal blood, just as occurs in the gills of the Amphibian tadpole, and of the Fish, which are bathed in water. The blood in the umbilical arteries of the embryo is, as we shall see, nearly all dark or venous blood; that in the maternal venous sinuses is really arterial, for the maternal portion of the placenta contains no capillaries, the branches of the uterine arteries which enter it terminating at once in the venous lacunæ, from which the true uterine veins pass obliquely. Having been properly purified and nourished, the embryonal blood returns from the placenta, enters the umbilical veins, and through them, reaches the embryo again. In the Reptile and Bird the respiration of the embryo takes place between the embryonal blood in the vessels of the allantois, and the atmospheric air in the fluids of the egg, or outside the shell-membrane; in neither Class do the vessels of the allantois or the branches of the umbillical vessels penetrate the outer coverings of the ovum, as occurs in the Mammalia generally.

The exact relations of the allantoid sac and its vessels with the chorion, and especially the extent to which it covers the interior of that coat, vary in the different Orders of Mammalia. In the Monotremata and Marsupialia, for example, the allantois is small and pear-shaped; its vessels are merely arborescent, and do not penetrate the chorion. Hence there is no special organ, or *placenta*, intermediate between the embryo and the uterine walls, and these animals are therefore named *Implacental* Mammalia.

In the porpoise, the pig, the horse, and, it is said, in the camel tribe also, every part of the chorion and the allantoid endochorion, which are coextensive, is covered with vascular processes; these enter the hypertrophied uterine membrane at all points, and form the so-called *diffused placenta*. In the Ruminants, with the possible exception of the camels, the vascular endochorion, or developed allantois, is also coextensive with the chorion; the vascular processes project, and attaching themselves to the uterus at certain definite scattered points of the surface, form the *embryonnl cotyledons;* these consist of clusters of *ramified* villi, which fit into corresponding ramified canals, arranged in cup-shaped depressions of the uterus, called the *maternal cotyledons*. No decidua exists in these cases, between the embryonal and the maternal tissues, and they are easily detached from each other. The blood in both is brought into close proximity, but the vessels of each are independent, and the two bloods do not intermingle. In the dog, cat, and Carnivora generally, the ovum, at first round, afterwards becomes oval, fusiform, or elongated, and occupies a compartment in the elongated uterus. The endochorion, or allantoid sac, is very extensive; but the villous processes, absent from the ends of the ovum, form a broad zone around its middle. A true decidua exists, and the combined structures constitute the *zonular placenta*. In the Rodentia, as is well seen in the rabbit, the allantoid sac reaches a small part only of the inner surface of the chorion; at this point alone permanent vascular processes are developed, which, entering the hypertrophied uterine membrane, part of which forms a decidua, constitute a *discoid placenta*.

In the formation of the *discoid human* placenta, it is noticed that the allantois is very small, appears early, and soon wastes; it reaches the chorion at only one point, not spreading out coextensively with it; and it conveys outwards, as usual, the umbilical arteries, the branches of which enter the permanent villous processes of the shaggy chorion, or fœtal villi; these are limited to one part of the ovum, penetrate the decidual and hypertrophied portion of the uterine walls, and enter the maternal venous sinuses.

The *two* umbilical arteries and *one* umbilical vein are supported upon the remains of the now impervious allantois, which grows into a soft mucous connective tissue; with these parts also are found the wasted vestiges of the vitelline duct, with its atrophied omphalo-mesenteric artery and veins; these structures becoming elongated, and surrounded with a tubular process of the amnion, form the umbilical cord or navel string. This cord is, therefore, connected with the placenta at one end, and with the navel of the embryo at the other. Its vessels are always more or less spirally twisted.

At the birth of the Mammalian embryo—an event which, with the human infant, happens at the end of the fortieth week—the fœtus and its membranes are detached from the inner surface of the uterus. The embryonal vascular portion of these membranes, whether it be a diffused, cotyledonous, zonular, or discoid placenta, is always detached. In the case of the zonular and discoid forms of placenta, where a true decidua is developed, a part of the maternal tissues is also separated at the same time. Where there is no decidua, as in the diffuse and cotyledonous forms, the fœtal villi are merely detached from the surfaces or recesses into which they fit. In the latter cases, parts of the maternal tissues, especially of the veins and venous lacunæ, come away. Hemorrhage is ordinarily quickly arrested, owing to the obliquity of the passages leading into the deeper uterine veins, and to the firm contraction of the uterine walls. If these become relaxed, arterial, but not venous, hemorrhage may occur.

DEVELOPMENT OF THE ORGANS.

The share taken by each of the three germinal layers of the blastoderm in the formation of the several systems of organs having been described, their special development may now be considered.

The Skeleton, Muscles, and Integuments of the Body.

The *vertebral column* is developed from the vertebral plates of the middle germinal layer, found on each side of the vertebral groove and chorda dorsalis. As the vertebral groove closes along the back of the embryo, first opposite the cervical and dorsal regions, small square masses are seen on each side of the median line, in the inner thicker portion of the vertebral plates. These were formerly considered to be the rudiments of the bodies of the vertebræ only, and were named the *primitive* or *primordial vertebræ;* but they are better named the *dorsal segments*, for other structures, besides the vertebræ, are developed from them. In the thoracic region, the posterior ends of the ribs, and, throughout the whole length of the vertebral column, the roots of the spinal nerves, together with the ganglia on the posterior roots, which are of great proportional size, the spinal muscles and the cutis covering these parts, are thus formed; a small portion only, therefore, is developed into the future vertebræ. The part which forms the skin and spinal muscles is named the *dorsal plate* or division, whilst the rest is called the *ventral plate* or division. The innermost portion of this latter, which is called the *vertebral* plate, grows inwards, and surrounds the chorda dorsalis, so as to inclose it in a thick, continuous, membranous sheath; this divides anew, transversely, into annular portions, corresponding with the bodies of the future cervical, dorsal, lumbar, sacral, and coccygeal vertebræ, into which they are developed, by passing first into a cartilaginous, and then into an osseous, state. The body of the atlas joins the axis, to form its odontoid process. The remains of the chorda dorsalis are traceable, for a long time, through the centre of the bodies of the vertebræ, but ultimately they become absorbed. In the lowest or Myxinoid Fishes, however, the chorda dorsalis is recognizable throughout life. Between the vertebræ thus formed, an intermediate soft tissue becomes developed into the *interver-*

tebral substances, in which the notochord persists, as the softer fibro-cartilaginous centre. Whilst the bodies of the vertebræ are thus produced, another portion of the dorsal division of the vertebral plates ascends towards the back of the embryo, grows around the vertebral groove, and then forms the *arches* and *spinous processes* of the vertebræ, so completing the vertebral column. These cartilaginous arches first close in the dorsal part of the column, and then meet everywhere, except opposite the coccyx, and sometimes at the lower end of the sacrum; the non-formation or non-union of these arches constitutes *spina bifida*.

At the anterior or *cephalic* end of the embryo, as already mentioned, the sides of the vertebral groove, composed of the medullary and vertebral plates of the external and middle germinal layers, expand, and, meeting above in the middle line, inclose a space which forms the rudiment of the cranium and its contents. This is soon marked off into *three pairs* of symmetrical sacs or dilatations, named the *cerebral vesicles*, which, bending down towards the yolk, form the *cephalic flexure*, or bend of the neck. In that part of the walls of these vesicles which corresponds with the middle germinal layer, the *cephalic capsule* or *primordial skull* is formed; this is at first membranous, then partly cartilaginous, and ultimately bony. Into the floor of this cavity, the anterior extremity of the cartilaginous notochord, or chorda dorsalis, penetrates only a short distance, reaching, in the middle line, as far forwards as the future sella turcica in the sphenoid bone, which lodges the pituitary body. The base only of the primordial skull becomes cartilaginous, like the bodies of the primitive vertebræ; the sides and upper part of the cephalic capsule remain membranous. The primordial skull does not divide into transverse segments, like the rudimentary annular vertebræ. Its cartilaginous portion is developed into the base and sides of the occipital bones or basi- and ex-occipitals, the alæ majores of the sphenoid or ali-sphenoids, and the pre-sphenoids and orbito-sphenoids or alæ minores, also into the *turbinate* bones, the *median portion of the ethmoid* bone, and the cartilaginous *nasal* septum. The *vomer*, however, is formed from a membrane, below the septum. The upper part of the *occipital* bone or supra-occipitals, the *parietal* bones, the *squamous* part of the *temporal* bones, the *frontal* bones, and the *nasal* bones, are developed as distinct *opercular* bones, directly from special centres of ossification in membrane, and not from cartilage. The *petrous* and *mastoid* parts of the temporal bone, and the floor of the tympanum, are developed from osseous centres in the basal cartilage; the *tympanic ring* arises from a fibro-cartilage, specially connected with the ear. The bones of the *face*, including the *upper* and *lower jaws*, also the *ossicles of the ear*, the *styloid* process of the temporal bone, and likewise the *hyoid* bony apparatus, are developed from the so-called *visceral* or *branchial arches*, which are formed, as will be hereafter described, from the lateral ventral plates of the cephalic portion of the embryo.

Opposite the trunk or body of the embryo, the outer or lateral part of the ventral plates extends downwards from the vertebral plates, to surround the hæmal cavity or future *thoracico-abdominal* chamber of the embryo. Within these plates, in the thoracic region, opaque lines appear, which ultimately form the *ribs;* where they close below in the middle line, the rudiments of the separate pieces of the *sternum* are developed; these may remain ununited in the middle line, constituting a rare and remarkable deformity—*fissura sterni*. In a similar manner, the *pelvic* or innominate bones, the *ilium*, *ischium*, and *pubes*, are found near the hinder part of the body; and the *scapular* arch, consisting of the *scapula* and *clavicle*, at the fore-part of the trunk.

A little later, the rudiments of the *limbs* appear, like small knobs, on each side of the trunk. In the centre of these, which consist of extensions of the middle germinal layer, the rudiments of the bones are soon seen, and ultimately become distinguishable as the bones of the arm, forearm, and hand, or of the thigh, leg, and foot. As the dorsal segments give origin, not only to the vertebræ, but also to the neighboring muscles and to the covering of the cutis, so the lateral plates, which produce the ribs and sternum, and the scapular and pelvic arches, and also the extensions of those plates which form the future limbs, not only give origin to the bones of those parts, but also to the corresponding muscles and cutis. The epidermis or cuticle covering all these parts, and, indeed, that of the whole body, is formed upon them by the common *external* germinal layer.

At first, the future skeletal parts are soft, and composed of cells but slightly differentiated from the rest of the cells of the germinal layer or blastoderm; by degrees, these parts become cartilaginous or membranous, and ultimately they undergo ossification. The process of ossification, with its order and times of occurrence, will be hereafter noticed.

Not only are all the muscles, and also the true skin thus developed, as well as the bones, ligaments, and joints, but likewise their respective vessels and lymphatics, and the nerves, both motor and sensory, which constitute the peripheral part of the spinal and cranial nerves, excepting those of special sense. The first muscles to be developed are those of the vertebral grooves, next the muscles of the neck, then those of the abdomen, afterwards those of the limbs, and lastly the facial muscles. The limbs are at first like simple buds, derived from the lateral plates; but they soon show divisions into their respective segments, and expand and flatten at their extremities; these next exhibit indentations corresponding with the future toes or fingers, which, for a time, are webbed. The upper limb is usually developed before, and more quickly than the lower one. The limbs are at first simple masses of blastema, which gradually change into cartilage, bone, muscle and skin. On the surface of the body and limbs, a layer of polygonal epidermic cells is very early traceable; this is the commencement of the cuticle. The papillæ of the skin, the rudiments of the hairs, feathers, nails or claws, and also of the cutaneous glands, afterwards appear.

The *mammary glands*, when first formed, resemble the cutaneous glands, consisting of solid processes derived from the epidermic layer, and penetrating the cutis; these afterwards branch out, and ultimately become hollowed to form the mammary ducts and vesicles.

The Brain and Spinal Cord.

The sides of the vertebral groove are lined on their surface by a special layer of blastema, known as the *medullary plates*, derived from the *external* germinal layer. When the groove and its cephalic expansion are closed, first in the neck, and then along the middle line of the back of the embryo, a *medullary canal* with a cephalic enlargement is formed; and the medullary plates, becoming thicker and growing from below upwards, are converted, subsequently to the appearance of cartilages in the rudimentary vertebræ, into a *tube* of *primitive nervous substance*, the anterior part of which is expanded into three vesicles, placed at first one behind the other, but afterwards bent with the head and neck of the embryo, and named the *anterior*, *middle* and *posterior*, *primary cerebral vesicles;* of these, the middle one is much the largest. From them are developed, respectively, the *prosencephalon*, the hinder part of which has been named the *diencephalon*, the *mesencephalon* and the *epencephalon*, of which latter the hinder part is called the *metencephalon*. The tubular portion of this medullary canal forms the *spinal cord*, which at first consists of numerous cells having a radiated arrangement around a central canal, and for a long time retains its hollow condition. Even in the perfectly-formed state, it presents a rudiment of this cavity, in the so-called *central canal of the spinal cord* (p. 249). The cells next to the canal form its epithelial lining, or *ependyma*, whilst the outer ones are developed into the nervous substance. The cord at first extends throughout the entire vertebral canal, but afterwards it grows in length less rapidly than the vertebral column, and the *cauda equina* is gradually formed. The substance of the embryonic spinal cord is composed of simple nucleated cells, which are developed chiefly into the gray substance of the cord, but partly also into fine connective tissue and bloodvessels. The white substance of the cord is subsequently formed. The peripheral part of the spinal nervous system, as already mentioned, is developed, with the framework of the head, trunk, and limbs, from the middle germinal layer.

From the *posterior cerebral vesicle*, at first smaller, but soon larger than the middle one, is evolved, in the *metencephalon* next to the spinal cord, the *medulla oblongata*. At this point, the nervous substance, developed from the primitive medullary plates, does not form a complete canal, as in the spinal cord, but remains open behind, constituting the fourth ventricle, and is marked on its floor by the calamus scriptorius, which leads into the canal of the spinal cord. Anterior to the medulla, but still in the posterior cerebral vesicle or *epencephalon*, appear the *pons*, and the *rudimentary cerebellum*, an angular projection forwards marking the line between them. At first, the cerebellum consists of a thin transverse plate of nervous substance; then it enlarges, and becomes laminated, the central part, or *vermiform process*, is recognized before the lateral parts, or *hemispheres;* the gray matter gradually becomes thicker on the surface, and the *corpora dentata* are formed within; the pons Varolii and the superior and inferior peduncles also gradually enlarge. Owing to the bend which occurs between the cephalic and cervical portion of the embryo, a posterior projecting angle is formed between the spinal cord and the posterior cerebral vesicle; this corresponds with the *cervical tuberosity* of the embryo. The *middle cervical vesicle*, or *mesencephalon*, slightly bent forwards and downwards across its middle, is, at first, the largest, but grows relatively slower than the others. After a time, it is developed, on its dorsal aspect, into the *corpora quadrigemina*, which form proportionally large masses, and are at first hollow—a condition which is permanent in Birds, but not in Mammalia. On the under-side, the *peduncles* of the cerebrum are formed; between these parts a cavity remains, which ultimately shrinks into the small canal connecting the fourth ventricle with the middle ventricles of the brain, named the *aqueduct of Sylvius*.

The *anterior cerebral vesicle* is, at first, more prominent laterally, though smaller, than the middle one; it is also at first smooth, but soon exhibits a median sulcus, and grows far more rapidly than the others, being destined to form the *cerebrum*. It soon bends directly downwards. The portion immediately in front of the middle vesicle, named the *diencephalon*, forms the two *optic thalami*, which originally consist of a single hollow mass, but afterwards become solid; they are divided by a fissure, which remains as the *third ventricle*, and communicates behind with the Sylvian aqueduct. The *pineal gland* is either an offshoot from the thalami, or it is derived from the pia mater. The optic nerve also originates in a part of this vesicle. The pituitary body, or hypophysis cerebri, in both its nervous part, and its posterior thyroid-like portion, is said to arise from the base of the brain, or to be in part developed from the pia mater. The *prosencephalon*, or portion of the anterior vesicle in front of the optic thalami, gives origin to the *corpora striata*, upon which the cerebral *hemispheres*, with the *corpus callosum*, the *fornix*, and the *ventricles*, are rapidly evolved. The corpora striata, and the hemispheres, are, it is said, at first separated by a slight constriction.

The hemispheres are developed from before backwards, leaving between them the cavity of the third and lateral ventricles, which, for a time, open freely into the yet hollow corpora quadrigemina. Gradually the hemispheres overlap the optic thalami, and then, in the higher Vertebrata, the corpora quadrigemina, and, lastly, even the cerebellum. At first smooth on the surface, and composed of thin walls inclosing a large cavity, the hemispheres, by degrees, become thicker, and marked on the surface with the *primary grooves* or *fissures*, which subdivide them into frontal, parietal, occipital temporal, and central lobes, and afterwards with the *secondary sulci* between the *convolutions*—the gray matter on the surface also gradually becoming thicker. The cerebral hemispheres, developed on each side of the middle line, are first connected only at their *base* and *anterior part*, by rudimentary commissural structures of nervous substance: these are the commencing peduncles, which may be traced, as white bands, upwards from the cord, the anterior commissure, and the rudimentary transverse commissure or corpus callosum. But, as the hemispheres grow backwards, the transverse commissural fibres of the latter extend in the same direction, and thus the future *corpus callosum* is formed with the *fornix*, composed of longitudinal fibres, beneath it, and the *septum lucidum*, inclosing the cavity of the fifth ventricle, between them. From the under-surface of the anterior part or frontal lobe of each hemisphere, a hollow process extends forward, forming the future *olfactory lobes*, the central cavities in which, in some animals, remain in communication with the ventricles of the hemispheres, but in others are obliterated. From the hinder and lateral part of the anterior cerebral vesicle, the *primary optic* or *ocular vesicle*, or rudimentary eye, is developed, forming connections with the optic thalamus and corpus quadrigeminum. From both these latter parts, which are then hollow, two tubular processes of nervous substance extend forward to the optic vesicles, and are ultimately developed into the optic tracts and optic nerves. Farther back, on the sides of the future medulla oblongata, are the primary *auditory sacs* or vesicles, which are not developed, like the ocular vesicles, as outgrowths of the cerebral vesicles, but commence on the surface of the embryo, as will be immediately described.

The membranes of the brain and cord are formed between the nervous centres and the walls of the cranial and spinal cavities. The pia mater is first recognizable.

The *sympathetic nervous system* is said to be developed from the middle germinal layer.

The Organs of the Senses.

The Nose.—As the olfactory lobes become consolidated, the nasal cavities, with the olfactory lining membrane, are developed, as inversions of the integument of the face, in the so-called primary olfactory groove. This, remaining open, becomes subdivided, to form the two nasal passages or fossæ. At one time, these fossæ are closed at the bottom, a condition which is permanent in Fishes; afterwards they communicate, in front of the palate, with the mouth, as in certain Amphibia; finally, they open only into the pharynx, as in Reptiles, Birds, and Mammals.

The Eye.—The *primary ocular* or *optic vesicles* commence, as already mentioned, as flask-shaped outgrowths of the first cerebral vesicle, with which they soon appear connected by a hollow stalk, the future optic tract and nerve. The interior of each optic vesicle quickly becomes lined with nervous substance. At the same time, the surface of the common integument covering the vesicle presents an inversion of the epidermic layer, which, becoming constricted at its orifice, closes and forms a sac; this is ultimately converted into the *capsule of the lens*, within which the lens-fibres are gradually developed, from radiating, epidermoid, nucleated cells. This growth, with other deeper tissues, pushes, as it were, the anterior and lower part of the nervous layer of the primary optic vesicle upwards and inwards, against the posterior and upper part, giving rise to a cup-shaped nervous expansion, open below, named the *secondary optic vesicle*, within which the *vitreous humor* is developed, this being also, like the lens, an integumentary structure. The sides of this secondary vesicle, consist of two layers, which subsequently blend, and their edges, at first separated below, close in that situation, include the central artery of the retina, and form the anterior part of the *optic nerve* and the retinal expansion. The anterior part of this secondary vesicle corresponds with the pars ciliaris of the retina, and gives origin to no nervous elements. The yellow spot does not appear until after birth. The outer coats of the eyeball, or the *sclerotic* and *cornea*, are partly growths of the secondary vesicles, and partly derived from the neighboring cutis. The *choroid coat*, also derived from the secondary vesicle, is at first adherent to the retina; the *iris*, growing at a later period from the margin of the choroid, forms an imperforate curtain, the central part of which, or *membrana pupillaris*, becomes transparent, then gradually loses its vessels, and finally disappears. The capsule of the lens is, for a time, invested by a vascular membrane, supplied by the central artery of the retina, and connected with the pupillary membrane and margin of the iris. The *aqueous humor* is secreted very late, the parts in front of the lens previously touching each other. For a time, the eyeball is simply covered with the integument, but this rises up, above and below, into small crescentic folds, which become the future *eyelids;* these, for a time, cohere at their edges, and then separate.

The Ear.—The *auditory sacs* are not developed, like the optic vesicles, from the cerebral vesicles, but, like the lens and its capsule, from inversions of the common integument. They commence by a little pit or depression, which afterwards becomes completely shut off from the surface, and, receding, is eventually attached to the side of the medulla. This primitive auditory sac forms the *sac of the labyrinth*, with which the auditory nerve, an independent formation from the medulla oblongata, is soon connected. From the sac of the labyrinth are gradually developed the membranous *semicircular canals*, and the winding *cochlea*, with the fluids in those cavities. All these parts are at first straight processes, but afterwards become curved or spiral. The cavity of the *tympanum*, with its ossicles, the tympanic bone, and the auricle, are formed externally to the deeper parts, in connection with the pharynx and Eustachian tube, as will be described with the development of the face. The *osseous* walls, which afterwards invest the *labyrinth*, are formed from the primitive cartilage of the base of the cranium. The *mastoid* process is not hollowed out into large air-cells until after puberty. The *external meatus* and the *auricle* are outgrowths of the annular fibro-cartilage, which forms the tympanic bone. The auditory gray nervous centre arises, near the posterior pyramid and restiform body of the medulla oblongata, as two masses, the outer one of which gradually moves backwards into the cerebellum itself. The auditory nerve consists of two portions, both of which become connected with these masses; but the anterior portion of the nerve also joins the superior peduncle of the cerebellum, and even reaches the inferior vermiform process. (L. Clarke.)

The Parts of the Face.

The extension downwards of the lateral ventral plates of the embryo, which, opposite the trunk, form the sides of the hæmal cavity, occurs also beneath the cephalic part. Here, however, where the future face is developed, the hæmal cavity is imperfectly closed in at the sides; for these plates, with their covering and lining membranes from the external and internal, or epidermic and intestinal germinal layers, split, on each side, into *four processes* or *lobes*, with little clefts between them, forming the so-called *visceral* or *branchial arches*, and the *visceral* or *branchial clefts*. The term branchial is applied to these arches, because the permanent gills or branchiæ of the Fish, and the corresponding temporary gills of the Amphibia, are developed from homologous parts; but in the embryos of the Reptile, Bird, and Mammal, these arches give rise, through very early metamorphoses, to other organs. Within them, minute, but important vessels, as will be hereafter seen, are temporarily present. Gills are never developed on them, and they never exercise a respiratory function. In these three last-named Classes, the allantois, a part not present in Amphibia and Fishes, is the embryonic respiratory organ.

The first branchial cleft, above the first arch, sometimes named the *maxillary cleft*, forms the cavities of the mouth and nose; these are originally conjoined, but subsequently become separated, by the growth of the upper jaw, from the substance of the first arch, between the nasal cavities above and the mouth below. The nasal walls and septum grow downwards from the cranium, whilst the upper jaw and palate are developed transversely from the face, to meet them. From the posterior part of the second branchial cleft, between the first and second branchial arches, are formed, the cavity of the tympanum, which at first contains soft connective tissue, the Eustachian tube, which is also at first filled with a similar tissue, the membrana tympani, and the external auditory meatus and its appendages. The auricle commences as a little ring around the margin of the meatus. The third and fourth branchial clefts completely close up, and disappear very early.

Within the branchial arches, little cartilaginous plates are soon developed. From the upper edge of the first of these arches a process is formed, named the *maxillary lobe*, from which the upper jaw is developed, together with the whole side of the face, including the internal pterygoid process and the palate-bone. The malar bones and lachrymal bones are formed as *opercular* bones. The first arch also gives origin, by another process, to the rudimentary *lower* jaw, and likewise, it is said, to the tongue. From the cranium, a median process, known as the *frontal process*, descends in the middle line of the face; and with this, an external and internal nasal process are also connected. These, by their junctions, form the walls and partition of the nasal fossæ, and the centre of the upper lip. In this latter part, the intermaxillary bones, which carry the upper incisor teeth, are independent formations. The lachrymal duct is a fissure which remains partly open, between the external cranial nasal process and the facial maxillary lobe. Sometimes these parts are arrested in development, and fail to unite properly, giving rise to the conditions of *harelip* and *cleft palate*. Certain other congenital defects, connected chiefly with the apertures of the body, as well as with the back of the head and spine, are explained by similar arrests of normal adhesive processes of development.

From the middle part of the first branchial arch, to which we now return, the incus of the tympanum is developed. From it, also, a remarkable cartilaginous process, named *Meckel's process*, or *Meckel's cartilage*, arises, which gives origin to the *malleus*, and also extends forwards from that bone to the rudimentary lower jaw, which is developed independently upon it, after the manner of the opercular bones of the cranium, which rest upon the basal bones. Afterwards, Meckel's process wastes, except a part, which forms the *processus gracilis of the malleus.* From the second branchial arch are developed the *stapes*, from a minute cartilage, and also the stapedius muscle, with its bony canal; these belong to the tympanic cavity. In the neck, the second arch forms the styloid process, the stylohyoid ligament, and the *little cornu* of the *hyoid* bone, which early unites with the tongue. The cartilage of the third branchial arch gives origin to the *great cornu* and *body* of the *hyoid* bone; but the arytenoid cartilage and the epiglottis are developed from the first arch. The fourth branchial arch soon coalesces with the side of the neck. All these changes occur very early in the pulmonated Vertebrata.

The Alimentary Canal.

The digestive canal is at first merely the interior of the body-cavity, which is formed by the folding downwards and inwards of the lateral ventral plates, and which, originally, communicates widely with the yolk-sac, by the open vitelline duct. The walls of this common body-cavity are derived principally from the middle germinal layer, but they are lined by the inner or intestinal germinal layer. It is a short, straight chamber, closed at both the cephalic and the caudal end of the embryo. Its innermost part soon separates from the sides of the embryo, and forms a tube, in which an abrupt *bend* occurs opposite the umbilical opening, and for a time projects through it, being there connected with the vitelline duct. In the Bird, this duct continues open, even after the chick is hatched; but in the Mammalian embryo, it soon becomes closed, and, attached to the primary bend of the alimentary canal, forms the slender *pedicle of the yolk-sac* or *umbilical vesicle.* The part of the canal, or tube above the bend, forms the pharynx, œsophagus, stomach, and a portion of the small intestine; the part below the bend, the remainder of the small intestine, and the large intestine: the distinction between these is soon indicated by the appearance of a cæcum, a little lower down than the bend. The closed upper end of this alimentary tube extends to the base of the cranium, corresponding with the pharynx, the œsophagus being continuous with it below. The lower closed end corresponds with the lower portion of the rectum. At a certain time, there is neither an oral nor an anal aperture. The buccal orifice is originally formed by a depression above the first branchial arch, and then opens into the pharynx, the tongue being already developed in its interior. At the lower end of the rectum, the anal orifice appears as a depression, which ultimately opens into the bowel. The *stomach* proper is, at first, a longitudinal dilatation of the alimentary tube, which gradually assumes an oblique, and then a transverse position. The primitive alimentary tube is closely attached to the vertebral column, and is covered by the peritoneum formed upon it and upon the walls of the cavity of the body, as it separates from the latter. But after the stomach has changed its position, the convolutions of the small intestine and the remarkable bend of the large intestine around them occur. These changes are owing to a greater development of the intestine than of the mesentery. This latter structure and the omenta are now fully formed. The small intestine is, for a time, wider than the large intestine. The vermiform appendix of the cæcum is, as it were, an incompletely developed, yet growing part of the large intestine. The valvulæ conniventes of the small intestine and the sacculi of the colon, appear afterwards. Fringed villi, at first, exist throughout the embryonic alimentary canal, but they are permanent only in the small intestine.

The Teeth.

In the cavity of the mouth, the middle and internal germinal layers give origin to the buccal *papillæ* and also to the *teeth*, which are themselves formed, partly by the corium, and partly by the epithelium of the buccal mucous membrane. At first, the rudimentary upper and lower jawbones of Man have no alveoli, and the membrane which covers their horseshoe-shaped borders is quite smooth. After a time, however, a groove appears on the margin of each maxillary bone, which gradually deepens and widens, and becomes separated by thin osseous septa into rudimentary alveoli.

In the meantime, according to one authority (Goodsir), the mucous membrane over the margin of the jaws also presents a groove, called the *primitive dental groove*, from the bottom of which minute *papillæ* arise, in the human jaw ten in number, above and below. These are the rudimentary pulps of the future milk teeth. Those of the upper jaw appear first. In each, the order of their appearance is as follow: the first molar, the canine, the central incisor, the lateral incisor, and the second molar. This is the *papillary* stage, which is soon converted into the *follicular* stage, by the rising up of membranous folds between and around the papillæ. By this time each papilla has enlarged, and assumed the form of the crown of the future tooth; whilst small membranous lids, or opercula, corresponding, in number and shape, to the surfaces of each tooth, overlap the papilla. Subsequently these follicles become deeper, and are closed by the adhesion of their opercula and by the union of the borders of the dental groove, and, at their upper part, a thicker portion is seen, which constitutes the *enamel organ*. The so-called *dental sacs* are thus formed, and the *saccular* stage is completed.

According to Kölliker and others, however, the dental papillæ, follicles, and sacs, are formed entirely beneath the epithelium over the jaw. The *enamel organ* is the part first developed, as a thickening of the deeper layers of the epithelium, which grows down into a flask-shaped depression, formed in the vascular layer or corium of the mucous membrane; the *papilla* then rises up as an extension from this membrane. By removing the epithelium, the dental groove, follicles, and opercula, of Goodsir are seen.

The form of the summit of the *papilla* being completed within the sac, a thin *cap of dentine* appears on it, which gradually increases at its edges, and becomes thickened on its inner surface, whilst the papilla, at first growing wider, but then contracting at its base to form the *cervix* of the tooth, continues to grow longer, and commences to form the *fang*, which shortly acquires its covering of *crusta petrosa*. In the meantime, by a separate process, the surface of the cap of dentine, on the crown, becomes covered by the growing *enamel*, formed from the *enamel organ*. At last, by the gradual growth of the fang, the tooth is pressed against the gum, which, becoming absorbed, the finished surface of the enamel is exposed, and the tooth is *cut*. The fang is now completed to its point, and the papilla, now called the *pulp*, remains as a vascular and nervous mass, occupying the pulp cavity, and receiving its vessels and nerves through an orifice left at the apex. In the meantime, the alveolus in the bone, has closely adapted itself to the fang.

In the growth of a tooth having *several* cusps and *fangs*, a separate shell of dentine and enamel forms on each cusp, the whole afterwards uniting; whilst the dentine shoots in at opposite points of the base of the pulp, where this begins to divide to form the separate fangs.

Behind the growing milk teeth, in each jaw, *recesses* are formed in the corium of the mucous membrane, which also become filled with epithelium, out of which future enamel organs are developed. Moreover, a vascular papilla arises from the bottom of these flask-shaped depressions or *cavities of reserve* (Goodsir), which finally close, and become the sacs of a like number of the permanent teeth. These sacs are at first oval, and adhere to the back of the sacs of the corresponding milk teeth, but afterwards they become more elongated, and recede from the gum, to which they are only attached by a fine cord or pedicle, found behind the necks of the other teeth. In this way, in Man, the ten anterior permanent teeth in each jaw, are developed. But the sacs for the three additional or superadded permanent teeth, on each side of the two jaws, viz., the sacs of the permanent molars, are formed by little *posterior cavities of reserve*, which appear on the edges of the jaws, behind the other teeth. These latter teeth are cut like the milk teeth. But the anterior permanent teeth emerge differently. Between the fang of the temporary tooth, and the sac of the corresponding permanent tooth, there is a thin layer of cancellated osseous tissue; and in this bone, is a little canal, which lodges the pedicle of the sac. The crown of a permanent tooth, being completed within its sac, its fang or fangs begin to be formed; the crown is pressed against the bony partition separating it from the fang of the milk tooth, and, when this is absorbed, against the fang itself. A peculiar, thick, pulpy, vascular areolar tissue intervenes between them, and appears to accomplish a gradual absorption, first of the crusta petrosa, afterwards of the dentine, and even of the lower part of the enamel of the milk tooth. Sometimes this process of absorption, which is not due merely to pressure, is temporarily interrupted, a renewed deposition of dentine taking place. At length, the side of the socket, the fang, neck, and even part of the crown of the milk tooth, having been absorbed, the tooth is loosened, hangs for a time by the gum, and finally drops out. The permanent tooth rises in its place; the crown appears above the gum, whilst the fang, closely followed by a consentaneous development and modelling of the osseous tissue of the jaw, becomes firmly fixed in its socket. The giving way and disappearance of the bone in one place, and its growth in other directions, by interstitial absorption and deposition, are remarkable examples of the plastic endowments of the osseous tissue.

The development of the teeth in the Mammalia conforms generally to the process above described.

The dentition of the Marsupialia, however, has lately been shown to be very peculiar. The only tooth which is successional is the *last premolar*, on each side of both jaws; it alone is preceded by a temporary tooth, which has a molar shape. The other teeth of the Marsupial jaw, not having any predecessors, might perhaps be regarded as themselves belonging to the *first* set, though not falling out; but this view seems contrary to the homologies of these teeth, which show them to be permanent. Perhaps in a very early stage of development, transitory rudiments of other temporary teeth may be met with in the forepart of the jaw of the Marsupials. (Flower.) The milk premolars of the guinea-pig are shed even before birth; the milk teeth of the Bats, Insectivora, and Seals are very simple and temporary; the first incisors of the elephant are very small, and the large incisors of the Rodents do not appear to have temporary predecessors.

The teeth are always parts of the *exo-* or *dermo-skeleton.* The replacement of the deciduous, by permanent teeth, occurs only once. But in the carnivorous Cetacea, the Edentata, and the Monotremata, there is no succession of teeth. Such animals are called Monophyodonts, the ordinary Mammalia being named Diphyodonts. The teeth of Reptiles and Fishes are also developed upon papillæ, and are mostly inclosed in sacs, or follicles, in certain cases, provided with an enamel organ; in the parrot fish, the rudiments of the teeth sink into alveoli; in the pike, they sink only into sacs or follicles; in the sharks and rays, they remain as papillæ on the surface, thus representing the papillary, follicular, saccular, and alveolar stages of development of the teeth of Mammalia.

The Digestive Glands, the Lungs, and the Spleen.

The mucous glands of the mouth, the salivary glands, the mucous glands and special tubular glands of the stomach and intestine, the liver and pancreas, and even the lungs, are developed from the middle and innermost germinal layers, the latter forming the epithelial lining of the several glandular organs. They usually commence by processes of epithelium, which sink into the corium, penetrate into numerous bud-like projections, corresponding with the future lobes and lobules of the gland, and are subsequently hollowed out, to form the ducts.

Thus, the *lungs* commence by two solid cellular processes, from the front of the œsophagus, which soon become hollow. These processes branch out into numerous, at first solid, but afterwards hollow, ramifications, which become lined by a ciliated epithelium, and form the bronchi, bronchia, and air-cells. The primitive lungs open separately into the pharynx, but afterwards by a common trachea. The trachea and larynx are produced by a lengthening out and excavation of a primitive peduncle, derived from the œsophageal walls: the larynx is developed from two lateral symmetrical masses of blastema, connected in front. Until the lungs are inflated at birth, they resemble a solid gland containing ducts with terminal acini; they then lie close to the back of the thorax.

The *liver* first appears, as two small conical projections of the corium and epithelial tissue, on the side of the intestine, below the stomach. These soon become hollow, and from them, numerous, solid, cylindrical branches extend into the growing matrix. Continuing to extend, these ramified masses of cells ultimately unite in a terminal network, and, becoming hollowed out, form the bile-ducts. The liver rapidly acquires a relatively large size, and is lobed; it soon even begins to secrete bile, or, at least, the coloring substance of the bile, for the biliary acids are said to be absent. The imperfect hepatic secretion enters the intestine of the embryo, forming the so-called *meconium.*

The *pancreas* is developed, in a similar manner, close to the spleen, by the formation of a small mass of cells from the epithelial layer on the left side of the intestine, which afterwards grows, and becomes canaliculated to form the pancreatic ducts.

The *spleen* commences near the great curvature of the stomach, but probably from a distinct blastodermic mass. The *thyroid* body appears as a similar small mass, in contact with the œsophageal lining membrane, in close connection with the commencing larynx. The *thymus* is said to originate *separately*, in front of the great vessels of the neck, as a delicate closed tube, which becomes diverticulated at the sides, and filled with nucleated cells and fluid.

The Urinary and Reproductive Organs.

The *bladder*, as already stated, is a part of the *urogenital sinus*, and is connected at its apex with the *urachus*, or obliterated abdominal portion of the allantois. It is developed originally, as a small pouch, connected with the lower end of the large intestine. The part of the intestine below the primitive communication with the bladder, forms a true *cloaca*, into which the digestive, urinary, and reproductive canals all open. The anterior part is soon separated from the proper intestinal portion by a septum which corresponds with the future perineum. It is this anterior part which forms, for a time, the *sinus urogenitalis*, the common outlet of the urinary and reproductive passages, and which becomes ultimately modified according to the sex.

Very early in embryo life, two remarkable symmetrical organs appear, at first as two linear elevations, one on each side of the primitive vertebræ, forming proportionally very large reddish masses, and reaching from opposite the heart to the lower end of the vertebral column. Originally, they consist of two symmetrical longitudinal canals, in the walls of which slight cæcal depressions speedily form. When fully developed, they consist of numerous comb-like, blind, hollow processes, lined with ciliated epithelium, very vascular, and communicating each with a long duct, which runs downwards, and opens into the genito-urinary sinus. Malpighian bodies, or arterial tufts, have been detected in them. These organs are the *Wolffian bodies*, or *primordial kidneys*, so called because their secretion contains, amongst other products, uric acid; in Fishes, they are said to become the future kidneys. In the Warm-blooded Vertebrata, they are in no way connected with the development of the kidneys, but rather with the first formation of the reproductive organs. Their secretion finds its way through the genito-urinary sinus, into the allantois, or future urinary bladder. They are proportionally larger in the lower Vertebrata, and persist for a longer time. At first highly vascular, they afterwards almost entirely disappear, as the proper kidneys are formed. The kidneys themselves commence as thick, smooth, or lobulated opaque masses, or processes of cells, arising from the sides of the cloaca, behind the Wolffian bodies; as these latter diminish, the kidneys enlarge, and gradually receding from the urogenital sinus and cloaca, assume their future normal position. They continue to be connected with the urogenital sinus, by a duct which forms the future *ureter*, *pelvis*, and *calyces*. The renal matrix at first contains bundles of solid processes, which afterwards become hollowed out, to form the tubuli uriniferi; these are said not to open originally into the pelvis of the kidney. The kidneys soon become lobulated, but afterwards smooth. Malpighian bodies appear in them very early. The suprarenal bodies are independent formations.

On the inner side, and somewhat behind each Wolffian body, appears, rather early, a little opaque mass, which is ultimately changed, according to the sex, into the *ovary* or the *spermatic gland*. Two ducts, the *ducts of Müller*, appear simultaneously, connected at their lower ends with the sinus urogenitalis, but terminating at their upper ends, at first, in blind extremities. In the male, these become connected with the spermatic gland, at the back of which, even in the adult condition, they sometimes present a long diverticulum. In this situation, too, vestiges of the Wolffian bodies may still be traced. (Giraldès). In the female, these ducts do not coalesce with the ovaries, but remain separate and form the oviducts of Fishes, Amphibia, Reptiles, and Birds, the left one only usually persisting in the adult condition, in the two last-named Classes. In the Mammalia, they constitute the free part of the Fallopian tube; between it and the ovary, are found, in the adult, vestiges of the Wolffian bodies. (Rosenmüller.) From the lower end of these tubes, and from the portion of the genito-urinary sinus into which these ducts open, the future uterus, or the prostate gland, is developed. In the Monotremata, an intermediate condition exists, approaching to the bird-like structure of the parts; for the two Fallopian tubes open separately into the urogenital sinus. In the Marsupials, and some Rodents, they combine before they open, forming a *double* uterus. In the Marsupials, remarkable pouches, the so-called *marsupia*, supported by special bones, are found in connection with the pelvic organs; they receive the young, which are born in an immature state. In other Rodents, the uterus is cleft. In the Cetacea, Solipeds, and Ruminants, the uterine chamber is double, or *two-horned;* in the Carnivora, Insectivora, and Cheiroptera, the horns of the uterus are comparatively short. In the apes, this organ is but slightly notched. The human uterus forms a simple triangular chamber.

The Heart, Bloodvessels, and Blood.

The first appearance of bloodvessels in the embryo and its appendages, can be best observed in the incubated hen's egg. In the middle germinal layer, where it extends over the yolk, linear clusters of nucleated cells appear, and arrange themselves in streaks, which soon unite in a retiform manner; these speedily become distinguished, by special processes of differentiation or development, into an external firmer part, or wall, which forms a future *bloodvessel*, and an internal softer part, which remains fluid, and further separates into liquor sanguinis and blood corpuscles, some of which are colorless, whilst others soon acquire the characteristic red coloring matter. The fluid central part of these red streaks is blood; it soon exhibits movement, and, as the vessels become connected, it forms continuous streams. These earliest vessels on the surface of the yolk constitute the so-called *vascular area;* they terminate in a marginal bloodvessel, known as the *sinus terminalis;* this, extending beyond the embryo, both in front and behind, divides into vessels which run towards each extremity of the embryo. In the meantime, in front of or beneath the chorda dorsalis, near the cephalic end of the embryo, within the middle germinal layer, a solid mass of cells appears, connected with certain branching streaks; the outer part of this becomes converted into an elongated sac or dilated tube, the primitive heart, and the interior into the liquor sanguinis and blood corpuscles; whilst from the connected streaks, are developed, an arterial trunk which divides into two branches, at the anterior end of the now tubular heart, and a venous trunk communicating with its hinder end. These rudiments of a propulsive organ or heart, with its embryonic arterial and venous channels, are, moreover, soon connected with the vessels already mentioned as being formed outside the embryo, in the vascular area upon the yolk, and thus a determinate direction is given to the blood circulating through the embryo and the surrounding vascular area. At this time, there are no capillaries in the embryo; all the vessels are either arterial or venous. The blood appears to pass out from the sides of the embryo, and to reach the terminal sinus, by which it is conveyed back in the direction of the cephalic end of the embryo. The *heart*, which originates very early—after the commencement of the second day in the chick—in a group of cells connected with the intestinal portion of the middle blastodermic layer, soon forms a straight longitudinal *utricle*, or *sac*, from the anterior end of which a short arterial trunk arises, the *bulbus arteriosus*. This speedily divides into two branches, which give off two anterior and two posterior vertebral arteries; the former supply the cephalic part of the embryo, and the latter soon unite, to form the descending aorta. The primitive aorta is very early connected with two small arteries, named the *omphalo-mesenteric* or *meseraic* arteries, which pass laterally on to the yolk-sac, hence they are also named *vitelline arteries*, and branch out into the vascular area; they convey the blood from the heart and body of the embryo, over the yolk-sac. After a time, one of these arteries disappears, the left usually remaining. From the vascular area, the blood is returned to the embryo, by the anterior recurved ends of the *terminal sinus*, which appears to have the function of a vein. But from the hinder part of the vascular area, other veins proceed, and end in posterior branches, which join the recurved ends of the terminal sinus to form the two *omphalo-mesenteric veins*; these enter the embryo, and become connected with the posterior extremity of the still straight, sac-like, heart. After a time, the right omphalo-mesenteric vein shrinks, the left one remaining pervious.

In the Bird, the vessels of the vascular area become very large, and form the *vitelline vessels*; they send vascular processes into the substance of the yolk, and thus food is absorbed by, and supplied to, the embryo. The yolk-sac is the temporary alimentary chamber of the embryo, and, in certain *lower* animals, it remains so; its vessels are represented by the abdominal veins in the Non-vertebrate forms. The vessels of the yolk persist in the Bird up to the period of hatching, and for some time afterwards, until the contents of the yolk-sac are completely absorbed. But in the Mammalian ovum, the omphalo-mesenteric artery and vein continue very small, and soon become obliterated. The circulation through the vascular area to the terminal sinus, in them, is probably chiefly respiratory.

But now a change takes place in the circulation outside the embryo both in the Bird and in the Mammal. The allantois grows, and two arteries proceeding from the posterior vertebrals, named the hypogastric or umbilical arteries, proceed out upon it; whilst two veins returning upon it, also named *umbilical*, join the common trunk of the omphalo-mesenteric veins. The right umbilical vein then disappears, and the left one, enlarging, as the single left omphalo-mesenteric vein diminishes, soon appears as the chief median vein, carrying the blood from the allantois, or its modification, the placenta, back to the heart of the embryo. It now passes through or beneath the liver. When the vitelline vessels, in the Mammalian embryo, have shrunk, the proximal part of the left omphalo-mesenteric vein, forms the trunk of the *portal* vein, and the part beyond this, after joining with the umbilical vein, constitutes the *ductus venosus*, with which vessels the liver and its veins are now seen to be connected.

As the embryo develops, the heart itself undergoes a process of bending or curvature, like an italic letter *S*. At the same time, it enlarges, and acquires thicker walls; the anterior or arterial part, which gives off the bulbus arteriosus, is now placed nearer to the under side of the embryo, whilst the posterior or venous part, which receives the conjoined veins, is turned backwards towards the vertebral column. The saccular *heart* is now marked off, by two constrictions, into *three chambers*, of which the first, or the one nearest the veins, soon exhibiting two superficial bulgings, corresponds with the *future auricles;* the second, also quickly showing an external line of subdivision, or notch, forms the *ventricles*, and the third, lying in front of and above the others, forms the bulbus arteriosus. Each of these quickly becomes subdivided. Thus, a *septum*, commencing on the anterior part, opposite to an external groove in its ventricular portion, grows upwards and backwards from the apex to the base of the heart, and ultimately divides it into the *right* and *left* ventricles. Some time after this, the septum between the *auricles* begins to appear, growing both from above and below, like two folds with crescentic margins; the edge of the upper fold, as it grows, keeps to the right side of the lower fold, so that the passage from one auricle to the other, named the *foramen ovale*, is more or less oblique. The septum is completed at the period of hatching of the chick, and of the birth of the Mammalian embryo. Lastly, the bulbus arteriosus becomes subdivided longitudinally into the pulmonary artery and the aorta, each remaining connected with its respective ventricle. The primitive heart, whilst it is still merely a straight tube, already manifests its proper function, its walls containing sarcous cells of round, oval, and fusiform shape, and distinctly contractile, the contractions soon being seen to proceed, in regular succession, from the hinder, or venous, to the anterior, or arterial end. Then, and even much later, when the heart is beginning to acquire its characteristic shape, its contractile walls present no distinct muscular fibres, but only large contractile nucleated cells, which are at first roundish, but afterwards become developed into spindle-shaped, or even forked, contractile fibre cells. The valves are developed, in their respective positions, from the inner surface of the heart, commencing very early.

The *arterial system* of the embryo is developed by the formation, and subsequent metamorphoses, of five arches on each side, which are formed in succession from the original arterial trunk at the anterior end of the heart, all, however, not being present at the same time. The arch first formed, consisting of the two branches into which the primitive arterial trunk divides, and which, curling backwards, unite along a part of their course to form the descending aorta, has already been described. Behind this first arch, a second, third, fourth, and fifth arterial arch are formed on each side, the first arch being obliterated before the last one appears; all in turn coalesce as they pass backwards, like the returning part of the first pair, to assist in forming the descending aorta. This is the condition which persists in Fishes, by which the trunks of their characteristic branchial vessels are formed (p. 692). In the higher Vertebrata, this state is very rapidly changed, and its several phases of development correspond with the adult condition of the Amphibia, and, in some respects, of Reptiles and Birds as well. These changes fully explain the mode of origin of all these varieties, from a common Vertebrate embryonal type. The upper primitive arterial arches, or primary arches, are said to occupy the third branchial or visceral arches or lobes, already described as appearing in the facial and cervical regions of the embryo. These arterial arches are thus modified: The *fifth*, or *posterior* arch, the last one formed, disappears on the right side; whilst, on the left, it constitutes the trunk of the future pulmonary artery, and joins the fourth arch. This *fourth* arch, on the left side, forms the left aortic arch, which, joining with the first, then descends and unites, in the Bird, with the corresponding or fourth arch of the right side, to form the aorta; but in the Mammal, the fourth arch, on the right side, does not form a right aortic arch, but remains pervious, as the innominate and the commencement of the right subclavian arteries, from which the vertebral and axillary arteries are given off. On the left side, the subclavian is given off directly from the fourth, or left aortic arch. The commencement or inner ends of the *third* arches, form the corresponding common carotids, whilst the third arches themselves remain as the internal carotids. The commencement or inner ends of the first and second arches become the external carotids, the transverse parts of the last-named arches entirely disappearing. (Rathkè.)

The *veins* of the embryo consist, at first, of four symmetrical *cardinal veins*, two anterior and two posterior, one on each side. The anterior and posterior vein of each side join to form the so-called right and left *ducts of Cuvier;* these again unite, in the middle line, into a very short trunk, which, at an early period, opens into the single auricle, and, except in Fishes, ultimately forms part of that cavity; hence, the two ducts of Cuvier open independently, as two superior venæ cavæ, into the auricle. This condition remains permanent in Birds and some of the lower Mammalia, which possess both a right and a left vena cava superior, opening separately into the right auricle. Instances are occasionally met with, from arrest of development, of two such veins in the human body. The anterior cardinal veins remain on each side, as the internal jugular vein. Between them, across the root of the neck, a transverse branch is very early formed, below the future subclavian veins. This cross branch, becoming enlarged, at the same time that the part of the left cardinal vein, extending below it down to the coronary veins on the back of the heart, is obliterated, conveys the blood from the left side of the head and upper limb, over to the venous trunk of the right side, and forms the future *left innominate* vein, the persistent venous trunk of the right side becoming the *vena cava superior.* The posterior cardinal veins originally return the blood from the Wolffian bodies, and from the hinder part of the embryo. These afterwards become the azygos veins, of which, however, the right one only remains in Man and the higher Mammalia, the left vein disappearing up to the back of the heart. Here, however, traces of the left cardinal *trunk*, or left vena cava superior, remain as the *cardiac sinus*, or the short dilated terminal portion of the great cardiac or coronary vein. Sometimes a smaller azygos vein, on the left side, ascending to the innominate, represents another portion of the primitive cardinal vein; from this point, however, down to the cardiac sinus, at the back of the heart, vestiges of the course of the primitive vein may be found throughout life. The left superior vena cava, when it exists, pursues the same course. The inferior vena cava is developed as a median vein accompanying the aorta, altogether independently of the posterior *lateral* cardinal veins. It is chiefly formed by the upper part of the omphalo-mesenteric trunk, which is joined by the umbilical vein, forming the ductus venosus; it also receives the common trunk of the future iliac veins. It terminates, at first, in the left half of the common auricle, but is soon shut off from that by the lower fold of the inter-auricular septum. The mode in which the pulmonary veins are formed, and brought into relation with the left auricle, is not known.

Embryonal and Fœtal Circulations.

The circulation established between the early embryo and the vascular area upon the yolk, has been called the *first embryonal* circulation; it is intended for nutrient and respiratory purposes. In the ovum of all the Vertebrata it soon ceases to be sufficient as a respiratory circulation. Thus, in the Fish and Amphibia, the branchial arches give origin to external or internal gills, which carry on the embryonic respiration; but in the Reptile, Bird, and Mammal, the allantoid sac is developed, the bloodvessels of which convey blood outwards from the body of the embryo, in order that it may be aerated, and then return it to the embryo again, thus assisting in the respiratory function. Moreover, in the Mammalian ovum, in which the yolk is so minute, the allantois and its vessels, as we have seen, assist in the formation of the *placenta*, which is not only a respiratory, but a nutrient organ. This *allantoid* or *placental* circulation constitutes what has been called the *second embryonal circulation.* It is thus carried on: From the iliac arteries of the embryo, the two *hypogastric* or *umbilical* arteries proceed outwards along the allantoid sac, and, in the eggs of the Reptile and Bird, ramify in the outer layer of the allantois, immediately beneath the permeable shell and shell-membrane. In the Mammalian embryo, the blood enters the membranous or villous placenta, and is returned by the single *umbilical vein*, which runs beneath the liver and joins the inferior vena cava just below the heart. In passing beneath the liver, the umbilical vein communicates freely with the portal vein. The blood brought back by the umbilical vein is *arterialized;* it partly enters the liver through its portal veins, and is thence returned by the hepatic veins to the inferior vena cava, but it is partly conducted on directly to this last-named vein, the portion of the venous trunk which so conducts the blood being named the *ductus venosus.* In the vena cava inferior, this mixed hepatic and arterial blood becomes further mingled with the venous blood from the hinder part of the embryo, and the combined stream then enters the right auricle, and here, guided by the Eustachian valve, is chiefly, and, in the earlier stages of development, entirely, conveyed through the foramen ovale in the auricular septum, directly into the left auricle. On the other hand, the purely venous blood returned from the anterior half of the embryo by the superior vena cava, separated by the same valve, remains in the right auricle. The contents of the auricles being, by their contraction, driven into the corresponding ventricles, it follows that the partially arterialized blood in the left auricle enters the left ventricle, and from it is propelled into the aorta and its branches, whilst the venous blood in the right auricle enters the right ventricle, and from it is propelled into the pulmonary artery. The pulmonary artery is, in the embryo, connected by a short arterial trunk, named the *ductus arteriosus*, with the under side of the arch of the aorta. Hence, the blood in the descending aorta, below that point, is mixed with the venous blood collected in the right auricle, whilst the arch of the aorta contains the arterialized blood collected in the left auricle. This latter blood is therefore conveyed by the great branches given off from the arch of the aorta to the anterior part of the embryo, *i. e.*, to the head, neck, and upper limbs; whilst the former, or non-arterialized blood, proceeds, in very small quantity, through the still narrow pulmonary artery into the collapsed lungs, but almost entirely through the descending aorta, iliac arteries and their branches, to the posterior part of the trunk of the embryo and the hinder limbs. A portion of it, however, is also conveyed along the hypogastric or umbilical arteries to the allantois, or placenta, to be once more renovated; from these parts it is then returned to the embryo by the umbilical vein, as arterialized blood, and pursues the course already described over again. The fœtal circulation is, therefore, largely accomplished by the action of the right ventricle, and the walls of this cavity, before birth, are of equal thickness with those of the left ventricle. The right auricle is then also larger and thicker than the left.

It is probable that, from the admixture of the venous blood of the embryo, at several points, with the arterialized blood brought from the allantois or placenta, no portion of the embryo is supplied with pure arterial blood, especially whilst the foramen ovale, between the auricles, is very patent. Nevertheless, the head and upper limbs always receive blood more perfectly oxygenated than that distributed to the lower half of the body. This difference is associated with the more rapid development of the important parts situated in the anterior half of the embryo. Thus, the head, the encephalon, and the organs of the senses, exhibit a far greater activity of development than the hinder portion of the embryo and the corresponding part of the nervous axis. The anterior limbs also show a greater relative development than the posterior. These conditions have even been regarded as having the relation of cause and effect; but probably they are merely associated conditions. As the heart approaches its perfect state, and the foramen ovale becomes smaller, and its course through the auricular septum more oblique, the arterialized blood is probably more completely conducted into the left auricle, and so, through the left ventricle, aorta, and great arteries, reaches more especially the anterior part of the body.

Change in the Circulation at Birth.

At the period when the young Reptile escapes from its egg, when the young Bird first chips the shell, and when the young Mammal is born, each begins to respire by the lungs. A modification of the circulation then becomes necessary, to connect it with, and adapt it to the newly-employed respiratory organs: the allantoid or placental circulations become arrested; the allantois is withered, and the placenta is first detached from the maternal system, and afterwards from the young animal, near the umbilicus or navel. From the umbilicus inwards, the umbilical vein shrinks on its coagulated contents, as far as the portal vein, and forms the future *round ligament* of the liver. From the portal vein to the inferior vena cava, the venous channel, called the *ductus venosvs*, likewise contracts on its coagulated blood, and is then obliterated, remaining only as a fibrous cord. The foramen ovale in the auricular septum becomes completely closed. The ductus arteriosus, connecting the pulmonary artery with the arch of the aorta, the primitive *ductus Botalli*, also contracts on its coagulated contents, and is soon converted into a fibrous cord; whilst the right and left divisions of the pulmonary artery leading to the lungs become enlarged, and convey a far larger quantity of blood than before; the pulmonary veins, which bring back the blood from the lungs to the left auricle, are, at the same time, proportionally enlarged. Lastly, the portions of the hypogastric arteries which pass upwards by the sides of the bladder and urachus, to issue at the umbilicus as the umbilical arteries, likewise shrink and become obliterated. By these changes, which are accomplished within three or four days, the circulation acquires its permanent condition, or what is called the *complete double circulation;* the venous blood, returned from the whole body, is propelled by the right auricle, exclusively into the right ventricle, and from thence, through the pulmonary artery and its right and left branches, entirely into the lungs. From these it is returned, arterialized, to the left auricle, is exclusively delivered into the left ventricle, and is thence propelled through the ascending and descending aorta and their branches, on to every part of the body. To complete these changes, the left ventricle, which now performs the whole work of the systemic circulation, speedily acquires a greater thickness of its walls than the right ventricle.

DEVELOPMENT OF THE TISSUES.

Animal and Vegetable Cells.

Whilst the forms and relations of the organs are evolved in the manner just detailed, their component tissues are undergoing development. These tissues, with their complex structure and composition, are gradually produced from simple, and originally identical, anatomical elements. They commence, like the organs which they build up, in the early periods of the formation of the embryo, originating directly from, or through the agency of, nucleated cells of the blastoderm, held together by an intermediate *matrix* or *blastema* (βλαστος, blastos, a germ). These cells are themselves the internal offspring of the contents of two cells—the germ cell and the sperm cell. The former, or nidal cell, fertilized by the latter, produces a brood of uniform cells, from which, by further multiplication and differentiation, all the tissues are evolved. These two cells are, originally, elementary histological parts of the tissues of parent animals, evolved by special developmental processes.

It is supposed by Schleiden, Schwann, and their followers, that all organized tissues, whether animal or vegetable, are produced directly from cells; but, though this is proved concerning the vegetable tissues, there are certain animal structures which, it would seem, are not formed out of such cells themselves, but are developed, for example, from the intercellular matrix or substance. Hence the so-called cell theory is regarded by many as exploded, so far as animal organisms are concerned. But if the definition of the term *cell* be extended, these discrepancies of view may be generally reconciled.

In a perfect vegetable cell, Figs. 46, 47, as seen detached in the vesicle of a microscopic fungus, or aggregated in the section of an onion, there is found a wall or *periplast* always composed of cellulose or lignin, with a contained *protoplasm* or *endoplast*, the outer part of which is often firmer than the interior, and is named the *primordial utricle;* in the endoplast is a *nucleus*, and in that, often, a *nucleolus;* around the nucleus is collected a soft, granular, *germinal matter*. In becoming *altered*, so as to constitute a vegetable tissue, these cells enlarge, change their shape, the nature of their walls or contents, and their connections or modes of junction, forming flat polygonal cells, polyhedral cells, elongated, fusiform, tubular, or reticular tubular tissue, plain, dotted, or spiral ducts, woody fibre, spores, zoosperms, pollen, or ovules. The intercellular substance is always scanty. For the formation of the tissue of a growing plant, such cells must also *multiply;* and this is effected by division of the cells, or by the formation of buds, or offshoots, which is much the same process, and resembles the fission or gemmation of non-sexual reproduction; but they can also multiply, as in the spore-cases of fungi, by internal or endogenous formation, which more resembles the sexual mode of reproduction. In the vegetable cell, the essential punctum or point, the centre of nutritive or developing force, is the nucleus or the nucleolus. It is this which appears to attract materials for the formation of the germinal matter around it, for the maintenance of the endoplast, and for the deposition of the periplast.

In animal cells, far greater variety of form and plasticity of function are observed. When in their most complete condition, as in the ovum, they consist, like a vegetable cell, of a cell-wall or envelope, the *periplast* of fluid or semifluid contents, the *endoplast* of a *nucleus*, and usually of one, two, or more *nucleoli*. The cell-wall is a thin, delicate, homogeneous, transparent membrane; but this is absent in many cells, such as the primary embryonic cells, and the white corpuscles of the blood, lymph, and chyle. The outer part of the endoplast is said sometimes to be firmer than the rest, and to constitute a special investment, like the primordial utricle of the vegetable cell. (Huxley.) In less perfect cells, there is often merely found a nucleus enveloped in a soft granular mass, as in the fusiform, unstriped muscle cell. The perfect cells may be called *cystoplasts;* the imperfect cells *gymnoplasts*. The cell contents of the former, or the cell substance of the latter, present, in certain cases, as in the primitive embryonic cells and in all newly-formed cells, besides fat particles, a peculiar semifluid, transparent, tenacious, albuminoid substance, called the *protoplasm*, which contains very minute molecules, and oleoid, and often amyloid matter. This protoplasm frequently presents movements, seen also in vegetable cells, which may depend on a contractility in the protoplasm, for it has been observed to be excited by electrical currents (p. 149). This protoplasm usually diminishes, becomes altered, or disappears, as the cell grows; but sometimes it is retained during its whole existence. It is very easily colored by carmine, and is thus made evident in microscopic investigations. The soft substance which gathers especially around the nucleus, corresponds with the *germinal matter* of Beale, which he regards as the *formative matter* of the cell, as distinguished from the special contents, or investments, which he names *formed* matter. The nucleus is a vesicular body, which in a growing cell is round or oval; its nucleolus is also, by some, said to be vesicular, but it may be, for a time at least, solid. These two structures are the essential parts, the essential *puncta* of the cell, the so-called germinal centres, or centres of cell nutrition and cell life.

It is supposed by Schwann that an animal cell may arise in the soft, clear substance known as *blastema*, a sort of *germinal matter;* that in this, by the development and collection of a number of minute molecules, a *nucleus*, called by him a *cytoblast*, is formed; and, lastly, that upon this a fine membrane grows, and gradually separating itself from the nucleus, forms the cell-wall, with its intermediate cell contents. This mode of origin is also supposed by Schwann to be the one by which new cells continue to be formed during the whole of life; but it is more commonly believed, that the nuclei of new cells proceed from the division or multiplication of pre-existing cells, and that all are the direct descendants of those originally formed in the ovum. The hypothesis of the *free* formation of cells is, as regards tissue life, the analogue of spontaneous generation, as regards animals themselves.

The formation of new animal cells from pre-existing cells, may take place in several ways. Thus the old or parent cell may divide into two cells; and in this case, the nucleus first separates into two, and the cell itself then presents an indentation across its centre, which, gradually increasing, divides it into two cells, each containing its proper nucleus; or sometimes the nucleus, instead of dividing into two, may divide into three, four, or, as has been noticed in the embryo of the frog, even into six nuclei, the cell itself then separating into a corresponding number of cells. This has been named the *fissiparous* mode of development. In the so-called *gemmiparous* development, new cells are described as being formed by the evolution and subsequent detachment of buds from the side of a cell. Instances occur, as in the soft medullary tissue in the interior of bones, and also it is said, in the spleen, of the formation, by repeated subdivision, of many nuclei in the interior of a single parent cell. In bone, these multiple nuclei of the cells remain as nuclei; but in the spleen, they may develop into an ordinary nucleated cell. *Free* nuclei are those which are *found* in a blastema or matrix, in very actively growing parts, or in morbid new growths; they originate from, or by the influence of, the old or pre-existing nuclei of the surrounding tissues, themselves the progeny of still anterior cells. They may appear to be evolved, in some way, from aggregations of protoplasm, but still, it is submitted, always under the influence of preformed nuclei or nucleoli. In the so-called *exogenous* development, rupture of the wall of the old cell occurs, the nuclei escape, and a new cell is developed from each. (Bennett.) The *endogenous* mode of formation consists in the increase in size of the old cell, a cleavage of the nucleus into two, and the development of two cells within the original cell-wall.

Animal cells undergo various changes in size and form (Fig. 122). Their nuclei, for example, may increase in size and alter in shape, but not to such an extent as the cells themselves; in many cells they become obscure; and in some cells, as in those of elastic tissue, they finally disappear. Their envelopes may expand and burst, or they may shrivel up and dry. The cells may dissolve or disappear, or be-

Fig. 122.

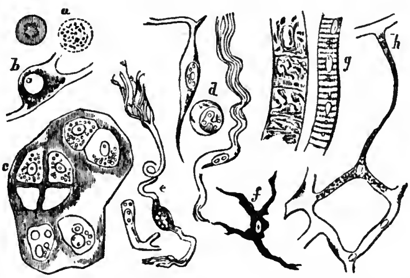

Fig. 122. Forms of animal nucleated cells. *a*, flat and round cell of red and white blood corpuscle. *b*, ramified cell of gray nervous matter. *c*, cells multiplying by binary division of nucleus and cell, and embedded in a solid matrix of cartilage. *d*, cells of areolar connective tissue, showing their splitting into fibrillæ. *e*, elastic fibre cells. *f*, ramified pigment cell. *g*, muscular fibres. *h*, capillary vessel.

come the seat of special deposits. Sometimes the substance of a cell undergoes but little apparent change; but usually, their contents are modified according to the tissue which they form, or the secretion which they prepare, *a*, *b*. Thus, some cells, as those of bone, dentine, and enamel, become loaded with earthy matter; others, as the red corpuscles, with iron in combination, and coloring substance; others, as those of adipose tissue, with fat; some with mucus or horny matter. Their relations to each other may undergo many modifications. In the fluids of the body, as *e. g.*, the blood, the cells remain separate. In the solid tissues, they may be simply connected together by a minute quantity of intercellular substance, as in the epithelium and epidermis. Sometimes they elongate, and form fibres in various ways, *d*; or, after lengthening, they may subsequently join with similar cells, and give rise to the formation of tubes. The septa between these may be absorbed, and the coalesced and arborescent branches of different hollowed cells may lead to the production of capillary, *h*, or lymphatic plexuses. Moreover, animal cells seem to exercise a singular power over the intercellular substance, blastema, or matrix, which often appears very large in quantity, in proportion to the cells themselves, as, for example, in cartilage, *c*. This matrix may be watery, soft and gelatinous, firmer and tenacious, still more solid and hyaline, or hard and opaque. It presents great varieties in chemical composition. It may be structureless, striated, fibrillated, fibrous, distinctly granular, or organically crystalline. Lastly, cells may undergo atrophy, or degenerate, become the seat of morbid deposits, especially of fat, and may finally die.

In contrasting the animal with the vegetable cell, it may be said that each vegetable cell, always a cystoplast, retains its own cell-wall, and is, in a certain sense, independent of the rest. The intermediate substance is either absent or invisible, or it takes the form of a separate periplast for every cell. Each cell is incased anatomically, and isolated physiologically. They cohere rather than co-operate.

As to the animal cells, they are sometimes cystoplasts, often gymnoplasts. The presence of a separate periplast is not universal; the endoplast, probably, has not even a primordial utricle; the outlying region of the cell is not specially protected, but the intermediate matrix, which may be a common periplast, is most abundant, and often curiously specialized in structure and composition. The cells are fused together rather than coherent, and they manifest great dependence on each other, less individual isolation of function, and more marked physiological co-operation.

Nevertheless, both animal and vegetable cells are organic bodies, living by the properties operating in their centres of growth and nutrition, the nucleus or nucleolus. The vegetable cell feeds upon inorganic materials, the animal cell on a pabulum of organic origin, but not on an organized pabulum. Organization only exists when, under the influence of nuclear, nucleolar, or cell action, the nutrient pabulum forms part of a living cell or its contents.

Development of the several Tissues.

Connective Tissue, and its varieties, areolar, fibrous, and jelly-like.

The embryonal connective tissue is a jelly-like substance, consisting of a transparent, soft, amorphous matrix, in which numerous nucleated cell-elements are found. According to one view, some of these cells elongate in the soft matrix, become fusiform, unite into long wavy bands, and then split into the fibrillæ of the fibrous or areolar forms of connective tissue, their nuclei being ultimately lost sight of. According to another explanation, the elongated cells and the matrix blend together into a homogeneous mass, which then becomes fibrillated, Fig. 122, *d*. In any case the nuclei remain as *connective tissue corpuscles*. In many situations, softish and nearly homogeneous tissues are met with, which are evidently modifications or arrested developments of connective tissue, as in the coats of small vessels, in the soft neurilemma of the smallest branches of nerves, in the submucous coat and villi of the small intestine, in the papillæ of the skin, and elsewhere. The cornea presents a peculiar form of fibrous connective tissue; whilst the vitreous humor is an imperfectly developed areolar tissue, in which the cells have gradually disappeared, or exist only at the surface, whilst the matrix has become deliquescent. The soft embryonal connective tissue and the vitreous humor contain no gelatin, but merely albumen and mucin. The chemical change into gelatin occurs only with the perfect development of this tissue. The cornea contains chondrin, and not gelatin.

Elastic Tissue.

In the development of this tissue, which is nearly always associated or intermixed with the connective, some of the cells of the embryonal tissue pass through the changes just described as proper to connective tissue cells, whilst others subsequently become much elongated and attenuated, branch out into fine ramifications, which unite with those of adjacent cells, undergoing similar changes, and preserve their nuclei in their central or thickest part. Sometimes these nuclei are ramified, at other times they are fusiform. In many situations, as in fibrous membranes, ligaments, and tendons, in the true skin, in the cornea of the eye, and elsewhere, these ramified and united cells remain in the above-described condition, their nuclei forming the connective tissue corpuscles. It has been said that they are hollow, and that their fine ramifications convey a nutrient plasma through the dense fibrous tissues in which they lie, and hence these have also been called *plasm-cells*. Lastly, they have been said to form the commencements of the lymphatics; but this is not proved. According to some, the intercellular substance becomes fibrillated, and appears to be a sort of deposit from, or an excretion upon, the nuclei or cells.

In other situations, as in the loose areolar connective tissue, these fine fibres appear darker, and form networks of elastic fibres. These reticular fibres, becoming thickened by a deposit on their outer surface, form the stronger varieties of elastic tissue; by being joined or further thickened in parallel planes, they give rise to the elastic fibrous networks of the air-tubes, or to flat fenestrated elastic membranes, as in the arteries. The true elastic fibres are said to lose their nuclei; but they may be merely covered in and hidden.

Adipose Tissue.

The vesicles of this tissue, however small or large, are obviously nucleated cells, in which fatty matter has accumulated; their nuclei become obscured, or even disappear. The fat-cells have been traced in all stages of development, from minute cells lying in the embryonal connective tissue, at first containing only an albuminous fluid, then a few scattered oil-drops, and finally attaining their fully distended condition. Other cells adjacent to them become changed into areolar connective tissue, bloodvessels, or lymphatics, which hold the fat-cells together, and minister to their nutrition. Often, when the fatty matter is absorbed from the cells, in emaciation, the nuclei again become visible. In the marrow of bones, the nucleated cell structure is very clearly and beautifully seen. The reddish parts of the marrow also contain smaller cells, and often compound nuclear cells, not fatty, called the *medullary cells;* these are very numerous in growing bone.

Cartilage, Fibro-Cartilage, and Yellow Cartilage.

The development of *cartilage* is more easily traceable than that of any other tissue, from nucleated cells which are the immediate descendants of the primitive embryonal cells. In the simplest form of cartilage, as in the *chorda dorsalis*, and in certain other embryonal cartilages, the cells have very delicate walls, which are closely applied together, grow into a polyhedral shape, and present at first no appreciable intermediate matrix. More commonly, as in the cartilaginous pieces which precede the formation of the bones, and in articular cartilage, the original delicate cell-walls acquire an outer deposit or secondary cell-wall, which goes on thickening, blends with that of other cells, and also with a surrounding intermediate matrix. This is partly formed by the secondary membranes, but partly, it is said, in the blastema between the cells. This matrix either remains transparent, or becomes granular, or even more or less fibrillated. The cells themselves enlarge, and new ones arise *within* them, by successive endogenous binary subdivisions of the nucleus, accompanied by corresponding constrictions of the cell itself. Moreover, secondary capsules are formed around each new cell, whilst the capsule of the parent cell is fused with the intercellular matrix, and so disappears. Fig. 122, *c*. The secondary capsules of the new cells, in their turn, blend with the matrix and cease to be visible, whilst fresh formations of still newer cells arise by division of their nuclei. The matrix thus formed is apparently homogeneous, but exhibits faint striæ on the application of reagents. Sometimes a nucleus, instead of dividing, and each new one forming a separate capsule, becomes invested by a series of concentric capsules, developed one within the other. Sometimes no secondary capsules are formed, the primary one only persisting. The contents of the growing cells become clearer, and the nucleus plainer. Amyloid substance has been found in young cartilage cells.

In *fibro*-cartilage, the intermediate matrix, with some of the cells, becomes changed into connective tissue, whilst other cells remain in the form of cartilage cells. In the *yellow* cartilages, intermediate elastic tissue fibres are developed between the cells, the rest of the matrix preserving its cartilaginous character.

Osseous Tissue and the Bones.

The mode of formation of perfect bone is exceedingly complex. It is never developed directly, but by the intervention either of *cartilage*, or of an imperfectly formed *fibrous connective* tissue, the *precursory tissues*, as they are called, in which *ossification* takes place.

In the *intra-cartilaginous* mode of origin of bone, the cartilage cells first rapidly multiply, by the formation of new cells within the old ones, giving rise to clusters of softish nucleated cells in a clear matrix. In a long bone, these cells are largest in the centre, and have their long diameter across the axis of the bone; as they grow, the matrix usually becomes faintly fibrillated. Wherever ossification is about to begin, there appear in the cartilage substance certain soft ramified spots, which consist of masses of smaller nucleated cells, out of which the bloodvessels and blood are formed; these ramified soft spots coalescing, form canals, whilst the contained bloodvessels, establishing communications with previously existing ones, supply blood to the cartilage about to undergo ossification. The cartilage cells are first grouped into elongated clusters, separated by a clear matrix; a deposition of earthy matter then takes place in this matrix between the cells, in the form of opaque granules, by which process the matrix becomes darker by transmitted light, and is soon calcified. This calcifying process partially affects the outer walls or secondary membranes of the cells, but not their contents.

The cartilage which is thus changed into bone, is called *cartilage of ossification*, *ossifying cartilage*, or *precursory cartilage*. The bony tissue into which it is converted, is called the *primary bone;* for it is no sooner formed than, as a general rule, it begins to be the seat of further important changes, during which it is almost entirely, or entirely, absorbed, to make way for the development of the *secondary bone*, or *perfect osseous tissue*. This last alone possesses lacunæ and canaliculi, concentric laminæ, Haversian canals, and their contained bloodvessels, cancelli, and in the case of the long bones, a central medullary cavity, with its vascular and medullary contents.

The change is thus accomplished. The primary bone is comparatively compact and opaque. In it, softer spots, or *areolæ*, appear, the *secondary cavities*, or *medullary spaces* (Müller), quite distinct from the ramified vascular canals in the precursory cartilage. These spaces appear to be formed by the junction of the adjacent clusters of cartilage cells, now disappearing, in consequence of the solution and absorption of the intermediate, dark, granular and calcified matrix. These areolæ contain, at first, a softish *ossifying blastema*, in which there very soon appear certain fresh nucleated cells, smaller than cartilage cells, and resembling *medullary cells;* besides these, there are developed an imperfectly formed fibrous connective tissue, and, likewise, many newly evolved bloodvessels. The adjacent areolæ being opened into each other, by the progressive absorption of the primary bone, their vessels become connected; and in their thinned walls the secondary or perfect bone is deposited, in successive layers, by the transformation of corresponding strata of the soft ossifying blastema and its contained cells. Hence the explanation of the concentric laminæ of the perfect bone. The indistinctly fibrous matrix of the ossifying blastema also becomes saturated with coalescing osseous granules, so as to appear perfectly transparent and homogeneous, instead of opaque and granular, like the primary bone. The entangled nucleated cells, the walls of which also become calcified, are believed to be converted into stellate cavities, by the partial intrusion of the calcifying process into them, and so to form the greater part of, or all, the bone *lacunæ*, whilst their radiating branches, multiplying, become very fine, and joining those of adjacent cells, form the *canaliculi*. The primary opaque granular bone contains no lacunæ. Some of the areolæ, or spots of solution, absorption, and new deposit, reduced in size by the successive formation of concentric laminæ of secondary bone around them, ultimately constitute certain of the Haversian canals; whilst others, even after they are lined by secondary bone, continue to widen by further solution and absorption of the surrounding bone, whether primary or secondary, and so form the larger nutrient foramina and canals, the small and large cancelli, and even the chief medullary cavity of a long bone. Indeed, so long as the bones themselves continue to grow, and even, but less evidently, throughout life, such processes of solution, absorption, and re-deposit are repeated, in the secondary bone, over and over again, as it is modified, by age, in size, form, and structure.

In the *intra-membranous* mode of origin of bone, there first appears, in connection with some previously developed fibrous membrane or *precursory membrane*, which afterwards forms the fibrous *periosteum*, a soft *matrix*, or *blastema*, which contains largish nucleated granular corpuscles, and soon puts on an indistinctly fibrous aspect; it resembles, indeed, imperfectly developed fibrous connective tissue. This fibrous matrix and the walls of its included cells become opaque by granular calcification. This occurring in successive strata forms the *bone* tissue; whilst the cavities of the cells, becoming stellate, with fine radiating and communicating branches, constitute the *lacunæ* and *canaliculi*. This process of calcification occurs from the first in a reticular manner. The fine spicula of the network increase in thickness, by the formation around them of a soft transparent *osteogenic* substance (Müller), which ultimately becomes bone. The granular corpuscles, or *osteoblasts*, are embedded in the new-formed bone. The interspaces, meshes, or areolæ, form softer spots, the constituent cells of which develop into blood-cells, bloodvessels, and areolar tissue, and, after changes in their parietes, such as those already described in speaking of the secondary bone tissue of bones preceded by precursory cartilage and primary bone, constitute the canals of Havers, the larger vascular foramina and canals, and the cancelli of the cancellated bony tissue.

Although, therefore, the intra-cartilaginous and intra-membranous modes of formation of bone differ from each other, the development of the secondary bone, which goes on, *pari passu*, with the absorption of the primary cartilage-formed bone, is analogous to the intra-membranous mode of ossification. The soft ossifying blastema, in the one case, and the precursory membrane, in the other, alike resemble an imperfectly formed fibrous connective tissue, and undergo similar changes. Chemical considerations also support this analogy, for, on removing the earthy matter from primary bone, its organic substance yields *chondrin*, whilst the animal basis of the secondary bone, and of the intra-membranous-formed bone, gives *gelatin* on being boiled.

The intra-membranous mode of ossification is solely concerned in the formation of the bones of the face, and of those of the upper part and sides of the cranium. The upper and lower jaw bones, the palate bones and vomer, the malar, nasal, and lachrymal bones, are included in this category; so also are the frontals and parietals, the squamous part of the temporals, the part of the occipital above the occipital eminence, and certain slight portions of the sphenoid. In the case of some of the cranial bones thus formed, the precursory membrane is developed outside a corresponding primordial cartilage, which is said to be afterwards absorbed. The cranial bones begin by one or more flat radiating *centres of ossification*, which spread out as the membrane advances, and go on increasing in thickness, until, at length, they meet at the different sutures; after this, they still continue to grow at their edges, until the cranium has reached its full size—an arrangement needed to suit the rapid growth of the brain. The clavicle is likewise in part formed from membrane, but afterwards in cartilage also.

The intra-cartilaginous mode of formation of bone occurs in the basal portions of the cranium, viz., in the ethmoid, in nearly the whole of the sphenoid, in the petrous and mastoid parts of the temporals, and in the occipital bone below the occipital eminence. It also occurs in all the rest of the skeleton, excepting only the clavicles. For each bone there is developed a separate precursory cartilage, which is inclosed in a definite perichondrium, and is at first small and rudimentary in form, but gradually acquires, as it grows, the general shape of the bone which is to be developed from it. Practically, therefore, the skeleton is, at first, and for a long time, more or less cartilaginous.

Certain *centres of ossification*, one, two, three, or even more, according to the size and form of the future bone, appear at definite spots in the cartilage, and extend into it as the latter increases in size. The cartilage continues to grow in the direction of the articular surfaces of the joints, and also in that of the various processes, until the development of the bone is complete. The bony tissue also goes on growing in the same direction, by the successive formation of the primary and secondary osseous tissue. But in other directions, and especially towards the sides of the bones, the precursory cartilages, sooner or later, cease to grow, and then the further increase in such directions is accomplished by intra-membranous ossification beneath the soft and growing periosteum.

Suppose in a long bone, for example, a single ossific centre to form in the middle of the precursory cartilaginous shaft, as indeed is always the case. Then, separate ossific centres subsequently appear at the ends, constituting what are termed *epiphyses* (επι epi, and φυω phuo, I grow), and in the larger bones, other smaller pieces are developed at the apices of the more remarkable projections or processes. The precursory cartilage of the bone at last ceases to grow in width, and, henceforth, the shaft of the growing bone is steadily increased in diameter, by successive subperiosteal intra-membranous deposits on its outer surface. At the same time, the medullary cavity is formed by a continuous absorption going on within. A platinum wire placed around the growing humerus or femur of a young pigeon, is found, after a time, inclosed in the substance of the bone, or, if examined a little later, in the hollow of the bone itself. But the precursory cartilage continues to grow in *length* long after, and the bony shaft, and the epiphyses developed at the ends, ultimately meet, but do not coalesce by osseous tissue until the full length of the bone has been attained. This is evidently a provision for securing a progressive elongation of the bone during many years, together with a proper development of the articular ends of the bones, all that time. At the ends of the bones, very thin layers of the precursory cartilage remain permanently unossified, and form the *articular cartilages* of the joints. Immediately beneath this articular cartilage is a thin stratum of *ossified cartilage* or *primary bone*, recognizable by being smoother and more compact than the rest. This is the only part of the primary bone which is permanent. The rest of this, and, indeed, the earliest formed, and many succeeding portions of the secondary bone, and also the subperiosteal intra-membranous bone, must be completely absorbed, before any long bone has completed its growth; for the young bone would easily lie in what becomes, by continuous absorption, the medullary cavity of the full-grown bone. The mode of increase in long bones is well shown by giving, at stated intervals, to young pigs or other animals, madder mixed with the food. The coloring matter of this root has an affinity for the salts of lime, and when it is being taken in the food, the bone then formed has a reddish tinge, whilst the bone deposited at other times is yellowish-white. By this means it is proved that successive additions are made at the surface and ends of the growing bone, and that absorption of the bone is continually taking place in its interior. Again, the distance between two holes made, one above the other, in a young bone, is not increased by its subsequent growth. (Hales, Hunter, Duhamel); whereas a ring of wire placed closely around a growing bone is soon found to be embedded in its substance, and at later periods, even in the medullary cavity. (Duhamel and others.)

Most of the smaller bones have but one ossific centre. In the large hip-bones, three primary ossific centres are formed, one each for the ilium, ischium, and os pubis ; these grow and finally coalesce around and at the bottom of the acetabulum. In the vertebræ generally, three primary ossific centres appear, and then join around the vertebral ring, the bone being afterwards completed by five epiphyses. In both these instances, and also in the case of the occipital foramen and the cranial cavity, the arrangement described facilitates the expansion of the cavity or canal around which the bones are destined to grow. The sternum is formed by the coalescence of many pieces. The cartilages of the ribs, and of the nose, are the unossified parts of the precursory costal and nasal cartilages. Sometimes the number of ossific centres has reference to the homological relations of the bone.

The order in which the ossific process begins in the various bones of the skeleton is very singular, not always coinciding with that in which the cartilaginous rudiments of the bones appear. The clavicles are the first bones to show ossific centres, and then the lower jaw, which has one in each lateral half. Next in order are the vertebræ, the humerus, the femur, the ribs, and the lower and larger portion of the occipital bone. Then, the upper jaw-bones, the frontal bone, the scapula, the radius and ulna, and the tibia and fibula. After that, most of the other cranial and facial bones ; the iliac bones, the metacarpus, the metatarsus, and the phalanges of the fingers and toes ; the ethmoid and turbinated bones, the sternum, the ischium and the os pubis ; the os calcis, and another of the tarsal bones, named the astragulus, and then the hyoid bone. At birth, and for some time afterwards, all the carpal bones, the five smaller tarsal bones, the last pieces of the coccyx, the patella, and the sesamoid bones, are still entirely cartilaginous, having no ossific centres in them. By the end of the fifth year, all these, except the scaphoid, trapezoid, and pisiform carpal bones, are ossifying, the last-named bone not showing any ossific deposit until the *twelfth* year. The various epiphyses of the long and and other bones are not all finally joined by osseous union to their respective shafts or chief masses, until after the completion of the full period of growth of the body, or about the twentieth or twenty-first year.

The Vertebrate Skeleton generally.—In examining the skeleton of the Vertebrate series of animals, progressive stages of development, from a cartilaginous to a more and more osseous condition, may be recognized. Low in the scale, as in the Amphioxus, the skeletal framework is composed of a hyaline substance, containing nucleated cells, between which are very fine fibres. In the Myxinoid fishes, it is composed of very distinct fibres, with cartilage cells intermixed. In the Chimæra, it consists, in some parts, of fibro-cartilage, and, in others, of cartilage. The vertebral column of the sturgeon is a mixture of cartilage, fibro-cartilage, and bone. In the skates and sharks, the cartilaginous skeleton is covered in parts, or entirely, with a crust of ossific matter. In the Lophius, the bones are fibrous and osseous. Lastly, in the so-called Osseous Fishes, the skeleton is entirely bony.

In the ossified parts of the skeleton of the Cartilaginous Fishes, the bony matter consists either of an irregular granular deposit, between and within the cartilage cells, or of polyhedral bone cells, or of ramified bony laminæ. In the less perfectly formed bone, neither lacunæ, canaliculi, laminæ, nor Haversian canals exist. In the more complete bone of the Osseous Fishes, those elements are introduced by degrees. The Haversian canals, in some cases, appear as a few long channels, from which simple canaliculi are given off. In a still higher structure, lacunæ, of a peculiar form, are introduced, of moderate size, tapering form, and sending out very short wide canaliculi. Frequently, the lacunæ of different layers of Fishes' bone, cross each other at acute angles ; but more commonly they are arranged in parallel lines. Sometimes no Haversian canals exist ; but usually they are present, though small. In rare instances, fine concentric lines are visible around these canals, representing rudimentary laminæ. In the lepidosiren, the lacunæ are very large, and the canaliculi much branched ; they thus approach the characters of bone in Amphibia.

In Amphibia, the skeleton is entirely osseous; the bony tissue presents large and wide lacunæ, very complex and ramified canaliculi, concentric laminæ, and Haversian canals. In a few situations, the lacunæ cross each other at acute angles.

In the Reptiles, and also in Amphibia and Fishes, the bones are solid, or contain but a few recesses filled with fat. The Haversian canals in Reptilian bone are small, the concentric laminæ irregular and wavy, the lacunæ of medium size and shorter than in the Fish, and the canaliculi very fine. Some lacunæ cross at acute angles, as in crocodiles.

In Birds, the lacunæ are smaller than in Reptiles, but larger than in Mammalia. In the latter animals, the bony structure resembles that of Man.

Muscular Tissue.

The fibres of both the smooth and the striped varieties of this tissue have been traced in their development from nucleated cells, derived immediately from the embryonal cells.

In the case of the *smooth* fibres, the nucleated cells, at first roundish, become elongated and fusiform; their cell-walls and their contents blend into one mass, which assumes, by degrees, the sarcous character; in the meantime, the nucleus of each fusiform cell becomes much elongated. Many such fusiform cells produce, by their cohesion, a smooth muscular band.

The *striped* muscular fibres have been described, by some, as arising, each from the coalescence of rows of nucleated cells. (Schwann.) But by other and more recent authorities, they are regarded as being each developed by the extreme growth of a single cell. (Remak, Fox.) It has also been maintained that they originate without the intervention of true cells, through the agency of rows of nuclei, lying in a blastema, which afterwards gives rise to the fibre by a series of changes occurring in it. (Savory.) These differences of opinion are probably as much due to the different interpretation of the same appearances by different observers, as to differences in the observations themselves. They illustrate the difficulties of microscopic research. If the primitive animal cell which forms a muscular fibre be regarded as a gymnoplast, easily fused with its neighbors, the discrepancy of opinion may, perhaps, be reconciled.

Supposing rows of nucleated cells to coalesce to form a single fibre, it is believed that the coalescing parts of the cell-walls are absorbed, and that thus a long tube is formed, which ultimately becomes the sarcolemma; the contents of the united cells, at first finely granular, are said to grow and become sarcous, their elements arranging themselves into linear and transverse series, first on the outer surface next to the sarcolemma, and then more centrally, so as to form the transversely marked fibrillæ. In the meantime, as the cells grow in length, the nuclei separate from each other, and become obscured, but are never lost. If, however, only one long cell forms each fibre, the wall of such an elongated cell is believed to constitute the sarcolemma, and the contents, originally granular, are said to be gradually increased and differentiated into the fibrillæ, first becoming marked by longitudinal lines, and afterwards by transverse striæ. The nuclei multiply by successive subdivisions, and remain surrounded by granular matter. By many, it is thought that the original cell-wall, or cell-walls, do not form the sarcolemma, but that this is the result of a subsequent deposit of a homogeneous membrane around the nearly perfectly formed bundle of fibrillæ.

Whatever their precise mode of origin may be, the muscular fibres seem, when first recognizable, like very fine bands, sometimes not more than one-tenth of the diameter of the fully formed fibre, and having bulging nuclei in them at intervals. When composed of such fibres, the young muscles resemble their tendons. As the fibres gradually increase in width, they assume the adult characters, and become uniform in diameter, so that the nuclei are no longer so easily visible (Fig. 122, *g*). At birth, all the muscles are said already to contain their full number of fibres, so that their future growth consists only in an increase of length and width of the pre-existing fibres. At birth, the fibres are about one-fifth of their ultimate dimensions. The fibrillæ of each fibre may during growth become a little wider; but it is thought rather that they increase in number. In other words, the individual sarcous elements retain their size, but they are accumulated in a greater number of longitudinal rows. In the enlargement of the muscles which takes place from exercise, in all probability the fibres do not increase in number, but in size, and contain either more or larger fibrillæ. In the opposite condition of the wasting of a muscle, the fibres remain the same in number, but become smaller, owing to a diminution of their contents; the fibrillæ also decrease in number, grow indistinct, or even disappear altogether. In a wholly paralyzed, unused, or diseased muscle, fatty matter is substituted for the characteristic sarcous elements.

It is obvious that such striped muscular fibres as, like those of the heart, are but indistinctly striated, may be regarded as less perfectly developed fibres. Certain of the smooth fibres, in which the sarcous elements are very distinctly granular, or dotted, also approach in character and development to the higher or striated form of fibre. The fusiform fibre cells, and last of all, the elongated, spindle-shaped, oval, or round contractile cells of the heart of the embryo, are the lowest form of all. There is thus a gradual transition from the simplest to the most complex form of muscle cells.

In the case of the ramified form of the striated muscular fibre, noticed in the tongue, lips, and face, of the reticular form observed in the walls of the adult heart, the primitive nucleated cells out of which they are developed, either simply ramify, or ramify and coalesce with the branches of other cells, and then acquire their sarcous contents.

Nervous Tissue.

The *ganglionic cells*, Fig. 122, *b*, are derived from metamorphosed embryo-cells, and from the direct descendants of those cells, by ordinary modes of multiplication. The rounded ganglionic cells are formed by a simple enlargement, and a gradual alteration of their contents; the nuclei persist, and are very distinct; the branched cells are formed by the outgrowth of one or more of the peculiar processes with which they are provided. The envelope is prolonged on to the processes, and becomes connected with the homogeneous tubules of the nerve fibres; the processes contain nervous substance. The very small rounded cells, and the free nuclei, found in some parts of the gray substance of the nervous centres, may be early stages of future ganglionic cells.

The *gray* or *gelatinous* fibres, found chiefly in the sympathetic system, whether they be regarded as true nervous elements, or as a peculiar form of connective tissue cells, appear to be produced by the coalescence of elongating fusiform nucleated cells, the contents of which, as the cells enlarge, become soft and finely granular, whilst the nuclei appear wider and wider apart. Even in the most highly developed of these fibres there is but little evidence of a tubular character or wall. The medullary sheath or fatty layer is absent. They have been compared, by some writers, to the non-medullated portions of the white nerve fibres, or to the axis cylinder or central band only of those fibres, which, however, have a tubular sheath. The most perfect gray fibres certainly resemble a transitory condition of the fibres out of which the white or tubular nerve fibres are developed.

The *white* dark-bordered, or double contoured *tubular fibres*, are themselves derived from fusiform nucleated cells, which are embryo cells, or their descendants. By coalescing, they first form gray granular fibres, with elongated nuclei at intervals, and, in that stage, resemble the gray or gelatinous fibres of the sympathetic system. But the grayish contents of these fibres soon become opaque and white, and resolve themselves into the central albuminoid band or axis cylinder, and then acquire the surrounding fatty layer or medullary sheath; whilst the walls of the coalesced cells are said to unite, to form the outer tubular membranous sheath of the perfect fibre. Instead of imagining many cells to coalesce, a single cell may be supposed to go on dividing, to form a nerve fibre.

The branched terminations of the nerves, according to what has been seen in the tadpole, originate in the junction of ramified formative cells, which keep on joining those already further developed.

Sometimes more than one white tubular fibre has been seen forming in a single embryonic, or less developed one—a fact which would show that the tubular membranous sheath might be developed otherwise than by the cell-walls of coalesced formative cells.

Bloodvessels.

The arteries and veins, excepting the very finest, are, as already mentioned, not so much tissues as compound structures, built up of several tissues. They are developed in two very different ways.

In the first place, the principal vascular trunks, or the *arteries* and *veins* of the germinal membrane of the embryo generally, and of its commencing organs, and indeed the *heart* itself, appear primitively as solid cords, composed of multitudes of embryonic nucleated cells. After a time, the innermost part or axis of these cords becomes changed into blood, the soft spaces coalescing and forming a system of canals; whilst the outermost cells are then gradually metamorphosed, in the ordinary manner, into the epithelial, elastic, muscular, and connective tissues which compose the coats of the vessels. This mode of formation is apparently limited to the early and principal vessels; for subsequently the arteries and veins, which are continuously being added, as the body grows, are developed in another manner—viz., by the transformatiom of previously constructed large-sized capillaries, the calibre of which is increased, whilst the coats are gradually thickened, by the formation of additional tissues developed in the ordinary way.

The capillary vessels originate in two modes, according to their size. The larger *capillaries* are formed by the coalescence of linear series of nucleated cells, and the subsequent absorption of their attached ends, so that a homogeneous tube is produced, recently shown to be lined with a fusiform epithelium, the nuclei of which seem to be attached to the walls of the vessels. These soon become connected with previously existing vessels, and the blood then enters them. The finer vessels, or those of the actual *capillary networks*, originate in nucleated formative cells, lying amongst the elements of a newly growing tissue; these become ramified or stellate, by sending out fine processes or branches, which run towards, meet, and coalesce with, other fine processes growing from the larger capillaries just described; afterwards they coalesce with processes of other ramifying cells which appear in succession. These coalesced processes and the cells themselves become progressively enlarged and hollowed out, so that a tubular or vascular network is produced, the component vessels of which, though, at first, so fine as to convey only the liquor sanguinis or plasma of the blood, become ultimately wide enough to carry the blood corpuscles also (Fig. 122, *h*). New capillaries may also be developed within the meshes formed by the older ones. The walls of the coalesced ramified cells constitute the homogeneous membrane of the coats of the capillaries, in which the nuclei of the formative cells, and especially those of the epithelial lining afterwards formed, can be recognized. The more numerous and closely set the stellate formative cells, the closer is the capillary network developed from them.

Blood.

This important fluid is primitively developed, as already mentioned, in the interior of the newly forming heart and principal vascular trunks. At first, its structural elements—*the blood-cells or corpuscles*, are colorless cells with faintly granular contents and a distinct nucleus, in all respects identical with the embryonic cells. They soon become loosened, and then separated from each other, by the formation of an intermediate fluid plasma, the new *liquor sanguinis;* their contents become less granular, and colored by the formation of coloring matter in their interior, but their nucleus remains. They are now red blood-corpuscles; but as compared with those of the fully formed blood, they are much larger, spherical instead of discoid, darker in color, and *nucleated*, instead of being destitute of a nucleus. Once formed, they speedily enlarge, elongate, or assume a somewhat flattened and elliptical figure, somewhat resembling the shape of the blood corpuscles of the Amphibia; the nucleus soon divides into two, or even into three or four portions, or young nuclei; the walls of the so altered cells then become constricted between these young nuclei, and, ultimately, the cells divide into as many new cells as there were nuclei; this process, it is supposed, may be repeated over and over again.

After a time, corresponding with the date at which the liver begins to grow, this process of subdivision of the primitive nucleated red corpuscles ceases, and then multitudes of colorless nucleated cells appear, especially in the blood of the liver and of the spleen, and also in the lymphatic system; and either without, or with, previous multiplication by subdivision of their nuclei, constriction of the cell-wall, and actual partition, they acquire, even within the spleen and liver, some red coloring matter, and are changed into *nucleated* red corpuscles.

Both sets of these spherical, nucleated red corpuscles, are ultimately converted, by a slight diminution of size, by a flattening of two opposite sides, and by the gradual wasting and final disappearance of the nucleus, into the typical *non-nucleated* disc-like red corpuscles of the fully formed blood. This condition exists at, or a considerable time before, birth. After birth, during the growth of the body, and in the adult, the red corpuscles of the blood are developed from the colorless ones, as already elsewhere described (p. 729).

The *white* blood-corpuscles are evidently the unaltered, colorless, nucleated cells, derived, at first, from the blood itself, afterwards from the liver, and permanently from the spleen and the lymphatic system. Under certain circumstances, as in inflammation, colorless blood-corpuscles may perhaps originate in the blood itself, within the general capillary system.

The *plasma* of the blood, at first the product of the liquefaction of the intermediate blastema or matrix, probably effected under the agency of the formative cells, is afterwards the complex result of various acts not only of a formative, but also of an absorptive and excretory kind.

Lymphatics or Absorbents.

The mode of formation of the principal absorbent trunk, the thoracic duct, is probably like that of the primitive bloodvessels.

The small *lymphatics*, according to observations made in the tadpole's tail, originate by the junction of nucleated cells, in the same way as the large capillaries; but they are said to anastomose much less frequently. The extension of the absorbents into newly growing tissues is effected, as in the case of the capillary network, by the formation in the new tissue of peculiar cells, which branch out, and join certain very fine processes, given off from the lymphatics already developed. These stellate cells are said to be more jagged in their outline than those of the capillaries.

The lymphatic *glands* are believed to be developed from clusters of lymphatic vessels, which give out projections, afterwards converted into the alveoli or cells of the cortical portion of those glands.

The chief microscopic structural elements of the lymph and chyle, the small and large nucleated *corpuscles*, most probably originate in the lymphatic vessels and glands, by subdivision of pre-existing corpuscles, and perhaps multiply by subdivision. Probably also some of those seen in the chyle and intestinal lymph, before it reaches the mesenteric glands, originate in the solitary or agminated glands. They also seem to be formed in the spleen, thyroid, and thymus glands, or even in the interior of the commencing lymphatics. At first, these cells are minute, and their envelope closely surrounds the nucleus. In this form, they constitute the small lymph corpuscles. They grow into the larger ones, by the deposition of soft granular matter between the exterior and the nucleus. They also multiply by elongation, subdivision of the nucleus, constriction of the delicate cell-substance, and partition into two new cells, each having its own nucleus.

The molecular base of the chyle is apparently the result of a process of aggregation of the simplest kind, whilst the fluid part of the lymph and chyle may be regarded as an extremely diffluent blastema or fluid matrix.

Vascular or Ductless Glands.

The several organs thus grouped together, arise from masses of primitive embryonic cells and blastema, which appear in the situations already described with their development as organs. The closed sacs of the lingual, tonsillar, pharyngeal, gastric, and solitary and agminated intestinal glands, and also the closed sacs or Malpighian corpuscles of the spleen, are developed by the multiplication of cells or cell-nuclei, of which the outer ones form a membranous envelope, and the inner ones the special pulp with its traversing bloodvessels. The cells of the thyroid body, and those of the suprarenal body, originate also by cell-growth, which is most readily observed in these peculiar organs. The new cells of the thyroid are said to be formed by a process of budding or protrusion, and subsequent constriction and separation. The parenchyma of the spleen, the thick walls of the recesses of the thymus, as well as its fluid contents, and lastly the pituitary body, are formed of gymnoplasts, nuclei, and a matrix.

Secreting Membranes and Glands.

The subcutaneous synovial bursæ, mere interspaces in the subcutaneous connective tissue, probably arise, at first, by a process of softening and absorption of that tissue, and afterwards by an extension of their walls. In the true synovial membranes, in the serous membranes, and in the mucous membranes, the defined *limiting* or *basement*-membrane is developed from very fine, almost homogeneous, connective tissue; but in the glands, the well-defined *glassy basement*-membrane is supposed to be a sort of excretion from the epithelial cells which cover the surface. The origin of the glands, as organs, has already been described. They commence as masses of nucleated cells, evidently destined to be epithelial; these project into and fill up recesses in the corium beneath. They either remain simple, as in the case of the gastric tubuli, or they may extend so as to develop the most complex gland, like the liver or kidney. The cavities of the ducts, which are at first solid, are formed by a softening of the intercellular matrix, along certain special lines of cells.

Epithelial and Epidermoid Tissues.

These arise, generally, from the multiplication and metamorphosis of the embryonic cells of the outer and inner germinal layer of the embryo. In the case of the serous membranes and of the synovial membranes of the joints, they also originate from cells in deeper portions of the embryonic structure.

The modifications which these cells undergo, however various, always permit them to retain their nucleated-cell character throughout their whole existence. The changes of shape, structure, and contents necessary to transform them into the various kinds of *epithelial* and *epidermoid* structures, can be understood by perusing the description of them in p. 65. Pigmentary deposits may occur either in simple epithelial cells (Fig. 43), or in ramified cells (Fig. 122, f).

In the many-layered epithelia, these changes may be seen at one view, all occurring simultaneously (Fig. 44). The cuticle at first cannot be distinguished from the cutis. All the epithelia, as well as the epidermis, exhibit a continuous growth. The glandular epithelia show the widest departure from the primitive cell-type, especially as regards the chemical composition of their contents. The mode in which cilia are developed on the ciliated epithelia, is not exactly known. It may be by outgrowths of the cell-wall, including processes of the cell-contents, or by a fission of the substance of the cell.

The *nails* are developed, not on the surface, but beneath a thin epidermic covering; the young nail consists of compressed and easily separable cells.

The *hairs* appear as little black specks under the cuticle; these are clusters of colored epidermic cells of the Malpighian layer, fitting into depressions in the cutis, which are lined by a basement-membrane. This rudimentary follicle enlarges, and acquires its flask-shaped character; its walls are formed by the thickened basement-membrane, and by a layer of cells belonging to the corium outside it. The outer epidermic cells form the root-sheaths, and the central ones, resting upon a little vascular papilla, develop into the hair. This increases in diameter and length, and then pierces the cuticle, beneath which it is really formed, sometimes by its point, and sometimes in a bent position. The first hairs are very fine, and form the down or *lanugo*. All new hairs, when old ones are to be shed, commence by a cluster of epidermic cells, formed at the bottom of the hair-follicle, upon the side of the old papilla ; as these grow, they detach the old and falling hairs.

Dental Tissues.

The *dentine* is a *dermoid bone*, formed by the gradual transformation and ossification of the superficial portion of the dental papillæ or pulps, and not by a mere excretion or deposit on their surface. The pulp is chiefly composed of rounded nucleated cells, in a clear matrix, but contains also a few areolar fibres, and many bloodvessels. The outer cells become lengthened, like columnar epithelial cells. By some it is thought that a single layer of these cells may, by elongations and other modifications, develop into the whole length of a dentinal tubule. It is more commonly supposed that successive layers of pulp-cells are developod, coalesce with each other, undergo metamorphosis, and become ossified, in order to complete a tubule. Lastly, it has been suggested, that rows of secondary cells developed within one primary cell, and subsequently coalescing, are so transformed. There are differences of statement as to the mode in which this occurs. The nuclei of these secondary cells are supposed to coalesce, and, remaining hollow, to form the dentinal tubuli. All the other parts of the cells and of the intermediate matrix become calcified, and constitute the walls of the tubuli and the intertubular dentinal substance. The fine bifurcated ends of the tubuli are formed by branching and anastomosing processes of the cells. Upon the surface of the growing dentine, next to the enamel, is seen a fine basement-membrane, named the *preformative membrane;* it is supposed to be the seat of commencing calcification, to be very early converted into the more compact superficial dentine, and to assist in connecting this with the enamel.

The *enamel*-organ (p. 970), consists of a soft pellucid tissue, entirely epithelial in its nature. It is composed, on its inner or deeper aspect, of a layer of columnar epithelial cells, which are applied to the preformative membrane of the dentine. Outside these is a thick stratum, composed of stellate cells, forming a network of fibres, inclosing multangular areolæ, filled with transparent substance, and having brilliant spots at the junctions of the fibres. Its outer part consists of epithelial cells, arranged in masses, between projections of the inclosing vascular mucous membrane. These masses are sometimes so large and prominent as to appear like white bodies beneath the gum, and have been erroneously regarded as glands—the *dental glands.* (Serres.) It is usually stated that the cells of the enamel-organ become elongated and calcified, with gradual absorption of their animal substance—at first forming a soft cretaceous mass, but afterwards becoming hard, and being firmly fixed to the surface of the preformative membrane. (Schwann, Kolliker, and others.) Their nuclei disappear, or leave only a fine linear trace. It has been supposed that the enamel-cells are developed beneath the preformative membrane (Huxley) ; but this view is not generally entertained. It is variously imagined that a single prismatic cell serves to form a single enamel prism, running through the whole thickness of that structure ; or that several secondary cells combine to form each prism. As the enamel-organ terminates at the cervix of the tooth, the formation of enamel is limited to the crown. The crusta petrosa is developed upon the fang, probably by intra-membranous ossification.

REPARATION.

The process by which injured or lost parts of the body are repaired or reproduced, so that similar tissues are, after a time, developed in their place, is known as *regeneration* or *reparation*. The formative power is here the same as that by which the embryo is first developed, and the developmental processes concerned are but extensions of those retained in mature life. This process of regeneration is most active during the earlier periods of existence. Thus, in cases of so-called spontaneous amputation occurring to the fœtus in utero, from constriction by the umbilical cord, fingers have been afterwards developed on the remaining portion of the limb. Instances, too, have been recorded, in which almost as remarkable re-formations of lost parts have occurred in infants, and even in children. In the same manner, the capacity of repair gradually diminishes as life advances, lost parts which, in early life, are regenerated, being afterwards imperfectly and incompletely reformed. Hence, in a child, the reparation of an injury may easily take place; whereas, in old age a similar lesion will remain unrepaired. Experiments have shown that the vigor and celerity of the repair of fractures, and the union of tendons in Mammalia, are in an inverse proportion to the age of the animal. (Paget.)

Amongst the lowest animals, the process of reparation after injury is identical with the process of reproduction by gemmation or fission. If the hydra be cut up into a number of small pieces, each of these becomes developed into a perfect hydra, and this process can be repeated, over and over again, with a similar result. The Annuloida likewise possess very great reparative powers; thus it has been noticed that the holothurida, when pulled about or injured, expel the whole of their viscera; after a few months, these are regenerated. Amongst the higher Non-vertebrate animals, however, in which reproduction by gemmation or fission does not occur, the power of reproducing a perfect body from a fragment does not exist. The Crustacea and Arachnida can, when fully developed, reproduce limbs and antennæ. In the Myriapoda, on the other hand, the reparative power ceases when they have reached their full development; whereas, previously to this, antennæ and limbs may be reproduced. The larvæ of Insects are endowed with like powers of reproduction; but the perfect Insects, at least the higher ones, have no such regenerative power. Hence, it appears that the amount of reparative power is in an inverse ratio to that of the development through which the animal has passed in its attainment of perfection. (Paget.) The reproductive power of the Mollusca has not been much investigated; it is said that the common snail can reproduce the head, if the cerebral ganglion be preserved. Amongst the Vertebrata, the Amphibia possess very great reparative power. After excision of an eye from the triton, or newt, a new one, it is said, may be developed in its place, and the reproduction of an entire limb, or of the tail, occurs readily in them.

But in Man and the Warm-blooded animals, the true reparative process is much more limited, being confined strictly to the reproduction of certain tissues.

In the first place, there are several parts, such as the epidermoid and epithelial tissues, and also the red corpuscles of the blood, which are naturally undergoing constant reparation or decay, and are as constantly being reproduced by what has been termed *continuous growth*, or *nutritive repetition*.

Secondly, certain tissues of comparatively simple structure and chemical composition, and of low vital endowments, appear to be capable of regeneration. Such are the areolar and fibrous tissues, elastic tissue, and bone, which fulfil mechanical uses in the body, serving to connect and support its various parts.

Lastly, bloodvessels, lymphatics, and nerves, tissues which penetrate other parts or organs, are likewise endowed with this power.

Other tissues and organs of a special kind, which have a complex structure, higher chemical constitution, or peculiar properties or functions—such as true cartilage, muscle, the gray substance of the nervous centres, the essential parts of the organs of special sensation, the cutis and its glands, the secreting and excreting glands, and the ductless glands—are not regenerated after injury or destruction.

The regeneration of particular tissues is accomplished by the multiplication and evolution of previously formed cell-elements, whether these be gymnoplasts, nuclei, or nucleoli; and by the modification of the intercellular or internuclear elements, or matrix, within the sphere of action of those nutritive centres. In this way, the *epidermis* and *epithelium* are speedily reproduced. The mode of formation of new *lymph-corpuscles* and *blood-corpuscles*, already described (p. 992), is to be explained in a similar way. The *connective*, membranous, fibrous, or tendinous areolar tissues, and the elastic tissues, are regenerated in the same manner as that in which they are developed. Connective tissue is the chief medium of restoration or repair in wounds, or ulcers of tissues or parts, which, like muscles, glands, and the cutis, are not reproduced. In its growth, it becomes penetrated by new capillaries and lymphatics, which are developed after the manner already described as their original mode of formation. The development of *new vessels*, in the meshes of effused lymph or blood, in the restoration of the lost tail or limbs of the Amphibia, and also in tumors, is accomplished in the same way. *Cartilage*, if removed by accident, or softened and absorbed in disease, is not regenerated, but cup-shaped cavities are left, which may wear smooth; if it be rent or broken across, it does not unite, but the separated parts become connected by strong fibrous or osseous belts. New cartilage is produced in certain tumors. *Bony tissue* is regenerated with remarkable facility; the process always takes place by the intra-membranous form of ossification. The intracartilaginous form, however, occurs in tumors. Injury to a *muscle*, such as division of its fibres, provided that the cut ends have not retracted too far from each other, is repaired by a uniting band of dense connective tissue, which re-establishes the continuity and office of the muscle; but when a whole muscle is torn across, it may retract, and form altogether new connections, or it may cease to be used, and then undergo fatty degeneration. A divided *nerve* is quickly united by connective tissue; in the cicatrix, nerve-fibres are afterwards formed, which join the divided fibres, and completely restore their functions, whether these be reflex, sensory, or motor. The nerve-fibres beyond the line of section usually lose their medullary substance or sheath, which previously undergoes a granular and fatty degeneration; but the tubular sheath, the axis-fibre, and the nuclei remain. When the ends of the nerve are once more united, the medullary sheath of the fibres is reformed, the reproductive process beginning at the cicatrix and extending downwards. In young animals, the medullary substance may be restored before the nerve is united.

GROWTH.

The human infant, especially, exhibits an imperfect and feeble condition at birth, and many changes, besides mere increase of size, take place in it, before it reaches the conditions of puberty and maturity. At birth, the average weight of the male infant is about 7lbs., and of the female infant about $6\frac{1}{3}$lbs. The lengths, in the two sexes, are about $18\frac{1}{2}$ inches and 18 inches. The nutritive vegetative functions alone exhibit a special activity, those of animal life proper being comparatively quiescent. The new-born child takes food, and sleeps; at first, it passes upwards of twenty hours out of the twenty-four, in a state of slumber; and during the first year, it requires from twelve to fifteen hours' repose. The respiration, circulation, and development of heat are relatively more active than in the adult; but the power of resisting cold is feeble, and hence protective clothing is necessary.

The general growth of the body is at first rapid, but afterwards much more gradual. Half the adult height is reached by about the end of the third year, whilst to attain the remaining half, fifteen or eighteen years more are required. At 20 years of age, a Man is rather more than $3\frac{1}{2}$ times his height, and about 20 times his weight, at birth. This growth is not equal in all parts of the body, the lower extremities, which were less developed in the embryo, now becoming proportionally more developed: on the other hand, not only the head but also many internal organs, such as the liver, kidneys, and supra-renal bodies, which are proportionally large at birth, afterwards grow relatively more slowly; the thymus gland even shrinks. The muscular system and the volitional power which commands it, are simultaneously developed and strengthened. At the end of the third month, the infant easily supports the weight of its head; at the fourth month, it is able to sit upright; at the ninth month, it crawls on the ground; before the end of a year, it can, with assistance, step; and at various times, from one to two years or more, it can stand, and begin to run alone. At six months, it can lisp, and, before the end of the year, can imitate a few definite articulate sounds of one or two syllables. The senses and the mind are gradually brought into exercise, hearing, as indicated by the effect of noises, before sight, as shown by the attractiveness of light- or of bright-colored objects. The development of sight, as a source of definite knowledge, under the education of touch, has been already fully explained. Of the other senses, perhaps, taste is the next to be developed, and after that, smell and touch. The order of appearance of the milk and permanent teeth, has already been detailed. The food of the infant, before it acquires teeth, is fluid, and the entrance of this into the stomach distends that organ, and completes its transverse direction; after the teeth appear, the food may be increased in density, from semifluid to more or less solid nutrient substances.

Life has been divided into periods, which may be physiologically thus distinguished. From birth to the appearance of the first tooth, the child or infant may be called a *suckling;* from thence to the time when the milk-teeth begin to fall out, is the period of *childhood;* thence to the period of puberty, is the age of *boyhood* or *girlhood;* from this to the final completion of the stature, is the epoch of *youth* or *maidenhood;* after that, is the period of *maturity.* Beyond this, comes the *decline of life*, and afterwards *old age.*

Puberty occurs in the male, at the age of from fifteen to eighteen, according to the climate, and the female, from twelve to fifteen. After the full stature has been attained, a certain development still goes on, the skeleton especially strengthening and solidifying itself, even up to the age of 25 in women, and 28 or more in men. At this period, also, the intellectual powers attain perfection, and the balance between assimilation and waste, is fully established.

DECAY AND DEATH.

The life of every organized being depends ultimately on the due and persistent performance of the tissue-changes. These are not only constantly wasting and undergoing repair, through the whole organism, by which means the life of the individual is maintained, but they degenerate and decay. Their nutritive energy becomes enfeebled; they are no longer renewed or repaired; their further development is arrested; the organs no longer perform their various functions; and then natural decline, *decay*, and finally *death* ensue.

Death may affect a tissue, or a part, or an organ only, of the body; it is accordingly said to be *molecular*, or *partial*, as the case may be; this is illustrated in *ulceration*, and *gangrene* or *mortification*, of the soft tissues, or *caries*, or *necrosis*, of bone. General death, called *somatic* death (ςῶμα, the body), affects the entire system. Partial or molecular death is only followed by general or somatic death, when it interferes with the processes of organic life. Somatic death is the result of a permanent arrest of the circulation. Besides this natural mode of death, or death from *old age*, or *climacteric* death, there are *unnatural*, *premature*, or *accidental* modes of death, which may occur at any period or moment. The immediate causes of accidental or unnatural somatic death, are *syncope*, *asphyxia*, and *coma;* these occur from injury or disease. Old age is the cause of natural somatic death. Coma and syncope have been alluded to in the Section on the Nervous System, p. 236, 282; and asphyxia is described at length under Respiration, p. 850. They may here be again briefly noticed.

In *syncope*, death begins at the heart, this organ either losing its irritability and power of contractility, or being affected with a tonic spasm. In the former case, it is found, after death, flabby and flaccid, with its cavities either filled with blood, or empty; in the latter case, it is firm and contracted, and almost or entirely empty. Death by syncope may be occasioned by widely different causes. Thus, it may take place through the nervous system, as when a violent shock or concussion is communicated to the body; it is in this mode, that strong mental emotion, as intense fear, joy, or grief, or sunstroke, lightning, extensive burns of the surface of the body, and sedative poisons, are fatal to life. The effects of many sedative poisons—as *e. g.*, of aconite, digitalis, and tobacco—are produced by the passage of the deleterious substance into the blood, and by the action of the blood, thus vitiated, on the nerves of the heart. Again, death by syncope may proceed from an enfeebled condition of the heart's substance, so that its contractile power gradually fails, a mode of death which is exceedingly common. It occurs in persons affected with disease of the tissues of the heart, especially in cases of fatty degeneration of this organ. Starvation (p. 909), exhausting diseases, and long-continued violent exertion, are further causes of death from feebleness of the heart's action. Lastly, this mode of death may occur from sudden and profuse hemorrhage, the circulation being arrested, not from loss of the contractile power of the heart, but owing to the insufficient quantity of blood which passes into its cavities. It takes place when a large bloodvessel is wounded, or when it is ruptured owing to disease of its coats, and in cases of profuse internal hemorrhage, as when an aneurism bursts.

Death by *asphyxia*, or suffocation, occurs when the movements of respiration, or the access of oxygen to the lungs, are arrested, the flow of blood through the pulmonary capillaries then ceasing. This mode of death occurs in cases of disease affecting the heart and lungs, and, though more rapidly, in choking, strangulation, and drowning. The breathing of carbonic acid and other poisonous gases, also kills by asphyxia; but this fatal result is due both to the absence of free oxygen and to the deleterious properties of the gas. The simple privation of atmospheric air, acts only indirectly on the heart; for the movements of this organ, and, indeed, even the pulsation of the smaller arteries, continue for a time, although all other signs of vitality have disappeared. The blood, as it traverses the pulmonary capillaries, now no longer undergoes the chemical changes essential to respiration, for it is non-aerated or venous, and cannot therefore sustain the functions of the various parts to which it is distributed. At first, it passes freely through the pulmonary veins to the left side of the heart, whence it is distributed through the arteries to the different parts of the body. Its noxious action on the brain is quickly shown by the rapid suspension of its sensorial functions, unconsciousness, and convulsions. The circulation in the pulmonary capillaries is at first gradually retarded, and at length totally arrested; so that the lungs are gorged, and the right side of the heart over-distended with venous blood, which passes into the left cavities of the heart in smaller and smaller quantities. Owing to this diminution in the supply of blood, and to its vitiated quality, the contractions of the heart become gradually more feeble, and finally all the vital actions are arrested. In the first stage of asphyxia, the face is livid, although voluntary, or instinctive and conscious, efforts are made to breathe, but without success. In the second stage, volition and even consciousness are lost, though convulsive movements are performed. In the third stage, all outward and respiratory movements have ceased, but the heart still beats. In an asphyxiated animal, the heart will beat for seven minutes, or three minutes after the arrest of external movements.

In *coma*, death begins at the brain, the sensorial functions being those which are first suspended. This mode of death occurs in fevers, in certain diseases of the brain, and in injuries of this organ, when these do not kill by shock or concussion. Thus, a person may receive a violent blow on the head. giving rise to symptoms of syncope; and after a time, although the heart regains its power, and respiration and circulation still continue, a state of profound stupor sets in, and death occurs in a comatose condition. Narcotic poisons, such as opium, belladonna, and chloroform, also produce death by inducing coma.

Death, however, frequently occurs in all these three modes. Thus, pressure on the brain, may not only induce coma, but also asphyxia and syncope, by paralyzing the medulla oblongata, from which the pneumogastric nerves, supplying the heart and lungs, arise. The fatal effects of chloroform, on the other hand, may depend on asphyxia, coma, or cardiac syncope.

Death from *old age*, or the *gradual decay of nature*, the natural mode of dying, is much less common than death from unnatural causes. Towards the decline of life, the formative power becomes defective; the processes of nutrition, growth, and development of the tissue-elements, no longer keep pace with the individual waste and death of these; so that the various organs of the body suffer a marked and gradually increasing structural deterioration or *degeneration*, and their functional powers are consequently diminished. These deteriorations or degenerations constitute *senile atrophy*, and are as natural and normal to the living organism as nutrition itself. The body either wastes and dries, or it grows fat, the individual either becoming emaciated or else corpulent. The coats of the arteries undergo fatty changes, the cornea exhibits the *arcus senilis*, and there is an increased quantity of fat in all the tissues and organs. The arteries become the seat of calcareous deposits, the bones contain an increased quantity of earthy salts, and the cartilages undergo ossification. The walls of the bloodvessels and other structures become thickened; the mucous membrane of the alimentary canal frequently presents an ash-colored appearance, and the lungs, even early, exhibit deposits of black pigment. Lastly, if disease or injury in no way interferes with the ordinary duration of life, the activity of all the functions slowly diminishes, until the vitality of the entire organism gradually becomes extinct.

The ordinary external appearances which indicate death, are, the cessation of breathing, the absence of pulse, a half-closed state of the eyelids with dilatation of the pupils, clenching of the jaws with slight protrusion of the tongue, and partial contraction of the fingers. The skin is cold and pale, or, if livid, is becoming paler. After a few days, a deceptive increase of color of the skin is sometimes noticed, owing to the blood being forced, by the evolution of gases from the larger central vessels, into the small vessels of the skin.

The only positive *signs* of *actual* death are those which depend on molecular change or death, viz., *rigidity* of the muscles of the whole body, and *putrefaction* of the tissues. These are most marked in organs and tissues, the vital functions of which are the most active. They supervene more rapidly in Warm- than in Cold-blooded animals. The action of the heart and the movements of respiration may be so much reduced, as to be altogether imperceptible, so that the functions of circulation and respiration appear to be arrested. This is occasionally observed in temporary syncope, in which a person, to all appearances dead, has, after a time, regained consciousness, and recovered. The peculiar condition of the nervous system called *catalepsy*, and the state of *trance*, are likewise further examples of so-called *apparent* death. But, as previously stated (p. 135), on the occurrence of actual death, the irritability of the muscles, by degrees, disappears, electricity no longer excites their contraction, and then cadaveric *rigidity* sets in. The time at which this comes on, its duration, and many other points connected with it, have also been there mentioned. The commencement of *putrefaction* is first indicated by the appearance of a bluish-green patch on the surface of the abdomen or thorax; this goes on increasing in size, and becomes brownish, the margins by which it spreads retaining, however, the primitive color. Putrefaction then shows itself in other parts of the body. The rapidity of this process presents great differences, the tissues being much more prone to putrefy after certain diseases; the temperature of the surrounding air also influences, considerably, the quickness with which the dead body is finally decomposed.

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