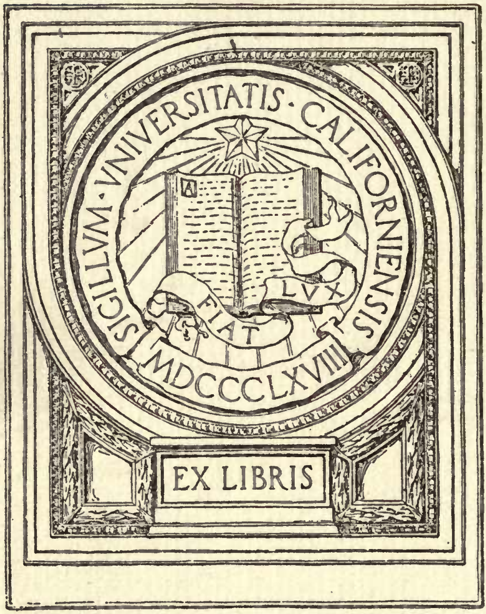
ELEMENTS OF PHYSIOLOGY

HOUGH AND SEDGWICK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ELEMENTS OF PHYSIOLOGY

BEING PART I OF "THE HUMAN MECHANISM: ITS PHYSIOLOGY AND HYGIENE AND THE SANITATION OF ITS SURROUNDINGS"

BY

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PREFACE TO THE REVISED EDITION

This edition presents a thorough revision, in which the authors have incorporated those advances in physiology which are directly applicable to the fundamental purpose of this book as stated in the preface to the first edition. Portions of certain chapters have been entirely rewritten, — notably those dealing with the work of organs and cells, internal secretions, digestion, nutrition, and the central nervous system.

The advances of physiological knowledge in the past decade have not only given clearer insight into the nature of the processes which underlie the phenomena of living things but have also made the facts of physiology increasingly helpful in the intelligent conduct of life. While this latter point of view has chiefly determined the selection of material to be included in this book, it has none the less been necessary to lay the foundation for the understanding of what we call the practical knowledge by a clear and succinct statement of the fundamental principles of physiology. This first part of "The Human Mechanism" therefore serves the purpose of those who cannot give the time necessary for the more extensive study of physiology required of the physician or the specialist in physiological science.

It is hoped that the interest aroused in the applications of physiology to the conduct of life may lead many readers of this book to the subsequent study of hygiene and sanitation. The second part of "The Human Mechanism" has therefore been published under the title "Hygiene and Sanitation."

We are indebted to Dr. E. P. Joslin for permission to reproduce from his work on "The Treatment of Diabetes Mellitus" the table on page 238.

PREFACE

The present book is a reprint of the physiological portion of our larger work entitled *The Human Mechanism*, together with Chapter XVI (Drugs, Alcohol, and Tobacco), which has been added to meet the requirements of law in some states with regard to the teaching of physiology. For those who desire in compact form the elements of physiology as a part of general biological training, as an introduction to the study of psychology, or for other special purposes, and for those who, having undertaken the study of hygiene and sanitation in *Elements of Hygiene and Sanitation* (Part II of *The Human Mechanism*), desire to acquaint themselves more fully with the fundamental physiology, the present volume should prove useful.

The references to Part II have been retained in the text, and apply either to *The Human Mechanism* or to *Elements of Hygiene and Sanitation.*

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THE HUMAN MECHANISM

PART I

ELEMENTS OF PHYSIOLOGY

PART I

CHAPTER I

THE HUMAN MECHANISM

1. The human body a living organism. The human body, as compared with bodies of water such as lakes and seas, or with heavenly bodies such as the sun, moon, and stars, is a small mass of matter weighing on the average, when fully grown, about 150 lb. and measuring in length about 5 ft. 9 in. It is neither very hot, as is the sun, nor warm in summer and cold in winter, as are many bodies of water, but in life and health has always almost exactly the same moderate temperature, namely, 98.6° F. or 37.5° C. The human body is not homogeneous, that is to say, alike in all its parts, as is the substance of a lake, but consists of very unlike parts — eyes, ears, legs, heart, brain, muscles, etc. — these parts being known as *organs*, and the whole body, therefore, as the human *organism.*

The most remarkable peculiarity of the human body, however, is that it is a *living* organism. A watch has unlike parts — spring, dial, hands, case, etc. — which are essentially its organs, and the watch might therefore be called an organism; yet it never is so called. We speak of a well-organized army, navy, government, society, church, or school, but never of a well-organized automobile, typewriter, printing press, or locomotive — apparently for the reason that in army, navy, or school living things play a principal part, while in mere machinery life is wholly wanting. The highest compliment we can pay to a machine is to say that it seems "almost alive," but it is not a compliment to any human being to describe him as "a mere machine." What the vital property is, what we mean by the terms "life" and "living," no one can exactly tell. About all we know of it is that some of the commonest elements of matter (carbon, hydrogen, oxygen, and nitrogen, with a little sulphur, phosphorus, and a few other elements) frequently occur combined as living matter, and that this living matter has marvelous powers of growth, repair, and reproduction, besides a certain spontaneity, originality, and independence, which lifeless matter never displays. "While there is life there is hope" for any plant or any animal, but this saying does not apply to any lifeless machine, however complex or wonderful.

2. The human body a living machine or mechanism. By a machine we mean an apparatus, either simple or complex, and usually composed of unlike parts, by means of which *power* received in one form is given out or applied in some other form. This power may be received, for example, in the form of heat, or electricity, or muscular effort, or as the potential energy of fuel; and it may be given out as heat, or electricity, or light, or sound, or as mechanical work, or in any one of many other ways. One of the simplest of all machines is a stove, an apparatus composed of a few simple parts by means of which the potential energy or power of fuel — wood, coal, gas, or oil — is liberated and applied as heat, for warming or cooking. A lamp is a still simpler machine in which the potential energy or power of gas or oil is liberated and converted into useful light. A candle is a lamp so simple that it almost ceases to be a machine, and yet the wick is really an apparatus for securing proper combustion of wax or tallow to provide good light.

Machines of greater complexity are watches or clocks, pieces of apparatus composed of many unlike parts which receive power in comparatively large amounts for a short time during the process of winding, store it as potential energy in coiled springs or lifted weights, and liberate it slowly in the mechanical work of moving the hands of the timepiece over a dial. Still more complex is a locomotive or an automobile, machines in which the power of coal, oil, gasoline, or other fuel or the electricity of a storage battery is applied to swift locomotion. But the most wonderful of all machines is the human body, a complicated piece of apparatus in which the power stored in foods, such as starch, sugar, butter, meat, milk, eggs, and fish, is transformed into that heat by which the body is warmed and into that muscular, nervous, digestive, or other work which it performs.

For delicate and intricate machinery the term "mechanism" is often employed, and we may therefore describe the human body either as the "human organism," or the "human machine," or, perhaps best of all, as the HUMAN MECHANISM.

The study or the science of the construction (structure) of this mechanism is called its *anatomy*; of its ordinary behavior, operation, or working, its *physiology*; of its proper management, protection, and care, its *hygiene.* This textbook is devoted chiefly to an account of its operation and care, that is, to its physiology and hygiene; but as any true comprehension of these subjects depends upon some preliminary knowledge of the parts of the mechanism itself, we shall begin by considering briefly the structure or anatomy of the human machine.

CHAPTER II

THE STRUCTURE (ANATOMY) OF THE HUMAN MECHANISM

Anatomy is studied partly by *dissection*, which reveals chiefly those organs which are visible to the naked eye, and partly by *microscopic examination*, which gives a deeper insight into the detailed arrangement of the cells and tissues of which the organs of the mechanism are composed. The present chapter is devoted to structures or organs shown by dissection — the *gross anatomy* of the body — as distinguished from its *microscopic anatomy* (*histology*).[1]

[1] Further explanation of the structure of the human machine will be given as it may be needed in subsequent chapters. At this point it is of the utmost importance that the student thoroughly master the general relations of the more important organs one to another; this, however, is not to be done by extensive reading, and still less by memorizing verbal descriptions; the aim should rather be to acquire from *figures and diagrams*, or better yet from *actual dissection*, where that is possible, a correct mental picture of the structures involved. Far more can be learned by constructing drawings or diagrams from memory than by the mere memorizing of text. The drawings may lack finish and may be at first difficult to execute; but so long as they represent the relations of the organs one to another they accomplish their purpose; beyond this point the more accurately they are drawn the better.

Moreover, drawing is a great aid to dissection. It not only fixes in the memory what is seen but it compels close observation; when one draws an object he is forced to note details and relations of structure which would otherwise escape observation. Nor is the freehand drawing which is required for our purpose so difficult as is often supposed by those who have never seriously used it. Let the student attempt to reproduce an object from his memory of its picture; begin with one which is not too complicated (such as the figure of the peritoneum and mesentery on page 14). Where he does not know how to represent a special structure, let him refer to the original, from which he may get suggestions; then close the book and draw from memory; any completed part of the work may be compared with the original and possible improvements discovered.

The human mechanism is composed of different parts, such as head, neck, trunk, arms, hands, legs, and feet, and each of these in its turn is composed of lesser parts. Arms and hands, for example, are covered by *skin*, which may be moved over underlying soft parts; at the ends of the fingers the place of the skin is taken by *nails*, while scattered over and emerging from its surface are *hairs*. Through the skin may be seen the *veins*, which may be emptied of the purplish *blood* they contain by pressing one finger on a part of the vein near the finger and pushing another finger along the vein toward the wrist; so long as pressure is maintained by both fingers the vein remains collapsed, but on removing the first finger it fills again with blood. Finally, through the soft parts (*flesh*) may be felt the hard *bones*. In general these various parts of which the body is composed are known as its *organs*, and because it possesses organs it is called an *organism* (p. 3).

1. The skin. The body is everywhere covered by a complex protective and sensitive organ, the skin. Only the eyes and nails seem to be exceptions; but as a matter of fact the exposed surface of the eye is covered by a very thin, transparent portion of the skin, and the nails are really modified portions of skin.

2. Subcutaneous connective tissue. On cutting through the skin we find that it is bound to the underlying flesh (chiefly *meat* or *muscle*) by what is known as *connective tissue*, the structure of which we shall study in the next chapter. Meanwhile we may notice that it contains blood vessels, that at some places it is more easily stretched than at others, and that when a flap of skin is pulled away from the muscles, this subcutaneous tissue fills with air. It often contains large quantities of fat.

Such practice may well precede drawing from an actual dissection and will pave the way to the latter. At all events let the student understand thoroughly that in the present chapter the figures, supplemented if possible by actual dissections, form the main objects of study; the text is strictly subordinate to the figures.

3. Muscles and deeper connective tissues.[1] The subcutaneous connective tissue sometimes connects or binds the skin directly to bone, as in parts of the head; usually, however, in the neck, trunk, and limbs the underlying tissue is the red flesh, or *muscle*, familiar to us as "lean of meat." If the skin be removed from the forearm, it at once becomes evident that this mass of meat or flesh is composed of a number of muscles which may be separated from one another more or less completely. In doing this it will be found that the muscles are held together by connective tissue in most respects quite similar to that immediately under the skin. Further dissection will show that one or another form of this tissue is the means of binding other organs together; thus the muscles are joined to the bones by a very dense, compact, and strong form known as *tendon*; the bones are united by a somewhat similar form known as *ligament*; and so on. The physical characters of the tissue differ widely, according to its situation and the use subserved; but one form shades more or less into another, and we have no difficulty in recognizing the general similarity which leads us to group them all together in one class.

4. Muscles attached to bones. When a muscle is carefully dissected away from neighboring muscles and other organs, it is almost always found that it is attached to one and usually to two bones; this union is frequently made by means of a *tendon*, as in the case of the large muscle of the calf of the leg, which is attached at one end to the bone of the thigh and at the other to that of the heel. A good example of the direct attachment of muscles to bones is furnished by those muscles which lie between the ribs (see

[1] The general appearance and arrangement of muscles, their attachment by means of tendons to bones, and the action of tendons on bones can be beautifully shown by a dissection of the leg of a chicken. The difference between trunk and limbs in the matter of the body cavity may also be readily demonstrated on the same animal.

Fig. 161). In either case the shortening of the muscle brings closer together the bones to which it is attached.

5. Definition of some anatomical terms. Before proceeding further we must agree upon the exact meaning of certain anatomical terms. We often speak of one part of the body as being "above" or "below," "before" or "behind," another. Such terms, however, are confusing, because their meaning depends upon the position of the body at the time they are used. For example, when one is lying on his back the head is *in front of*, or *before*, the trunk; but when he is standing on his feet it is *above* the trunk.

Now the body is certainly divided into right and left halves, which are much alike externally, though this likeness is not so marked in the internal parts. *Right* and *left* then have their ordinary meanings, and that without regard to the various positions the body may take.

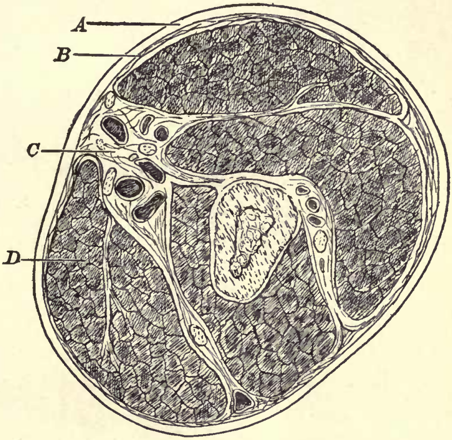


FIG. 1. Cross section of arm

A, skin; *B*, subcutaneous connective tissue, binding the skin to the muscles *D* and continuous with the connective tissue which binds together the muscles; *C*, blood vessels and nerves

To indicate that any part is nearer the head than another part, we say that the former is *anterior* to the latter; to indicate that the latter is further away from the head, we say it is *posterior* to the former.

Finally, the region popularly known as the *back* is called *dorsal* (Latin *dorsum*, "back"), that opposite the back being called *ventral* (Latin *venter*, "belly"). Thus the nose is on the ventral side of the head; the toes are at the posterior extremity of the foot.

P

6. The body cavities. There is one striking and important structural difference between the trunk and the limbs; the former contains a central body cavity, completely filled, however, with various organs, while the arms and legs are each composed of a continuous mass of tissues, namely, muscle, blood vessels, nerves, bone, etc., all bound together by connective tissue (Figs. 1 and 2).

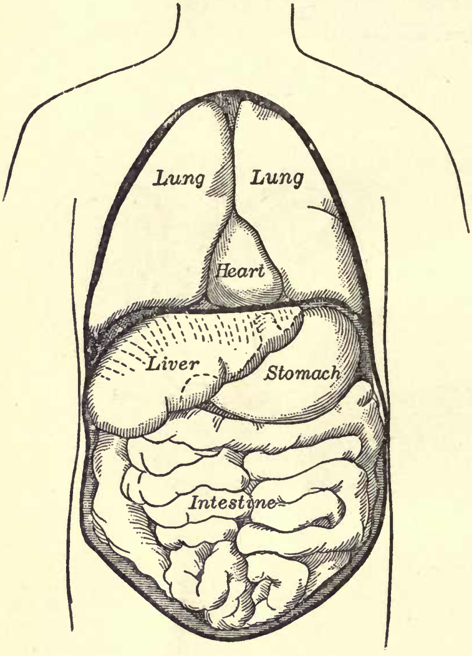


Fig. 2. The thoracic, or pleural, and the abdominal, or peritoneal, cavities filled with organs

The cavity of the trunk, or body cavity, is subdivided transversely by the dome-shaped muscle known as the *diaphragm* into two cavities — an anterior, known as the *thoracic*, or *pleural*, *cavity*; and a posterior, known as the *abdominal*, or *peritoneal*, *cavity*. Both cavities are lined by a thin, smooth, shiny membrane, that of the thoracic being known as the *pleura*, and that of the abdominal as the *peritoneum*.

Filling the pleural cavity are found the *heart*, *lungs*, *œsophagus*, *windpipe* (or *trachea*), and many great *blood vessels*; filling the abdominal cavity, the *stomach*, the *small intestine*, the *large intestine*, the *liver*, the *pancreas*, the *kidneys*, the *spleen*, and other organs, together with numerous large and important *arteries* and *veins.* In both cavities the lining membrane (pleura or peritoneum) is folded back over the organs; that is to say, the organs do not really lie *in* the cavities, but only fill them as the hand would fill a bladder one wall of which it pushes in against the other. The surfaces of the organs, like the walls of the cavity, are consequently smoothly covered and glide over one another with very little friction. The preservation of these pleural and peritoneal linings in their normal condition is a matter of great importance; when inflamed or otherwise injured their surfaces become roughened, and *adhesions* of connective tissue often develop between them which fasten the organs together or to the walls of the cavity, so that surgical interference is sometimes necessary. Pleurisy is such an inflammation of the pleura, peritonitis of the peritoneum; and both are very serious conditions.

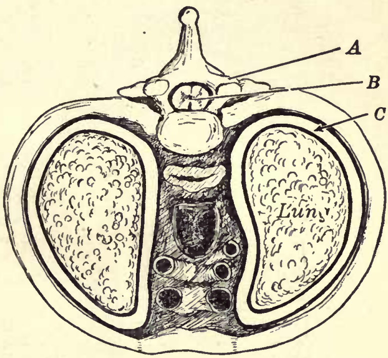


FIG. 3. Cross section of the chest anterior to the branching of the trachea

A, a vertebra of the spinal column; *B*, spinal cord; *C*, the pleural cavity (which is exaggerated for the sake of clearness, the surface of the lung being actually in contact with the body wall). The œsophagus, trachea, together with several large arteries and veins, are shown in the mediastinum ventral to the vertebra and in the order named

7. Attachment of the organs to the walls of the pleural and peritoneal cavities. The pleural cavity is completely divided by a median partition of connective tissue (the *mediastinum*), within which are found the *trachea*, the *œsophagus*, the *great blood vessels*, and — lying within a special cavity of its own — the *heart.* Approximately halfway from the anterior to the posterior border of the mediastinum the trachea divides within that membrane into two tubes, or *bronchi*, which pass through the mediastinum outward, one to the *right lung*, the other to the *left*. The pleural lining of the mediastinum is pushed outward by these tubes and, as they end in the lungs, forms the pleural covering of the latter (Fig. 5). Consequently the organs of the pleural cavity either lie within the mediastinum (heart, œsophagus,

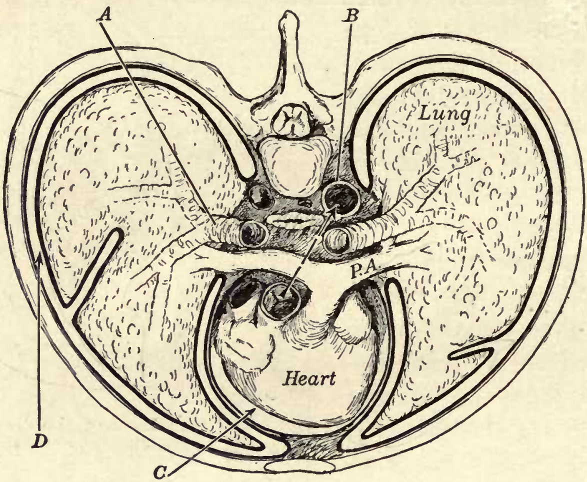


Fig. 4. Cross section of chest posterior to branching of trachea

***A*, bronchus, entering the lung; *B*, the aorta cut at its origin and again at the descending part of its arch; *C*, the pericardial space; *D*, the pleural cavity; *P.A.*, the pulmonary artery**

trachea, etc.) or else are covered by extensions of the mediastinal pleura (bronchi and lungs).

The abdominal cavity is not similarly separated into right and left halves; but a membrane, the *mesentery*, passes ventrally from the dorsal wall to the stomach and intestine, which are slung in it somewhat as a man lies in a hammock. The line of attachment of this mesentery to the small intestine is much longer than that of its attachment to the body wall; hence it has the general shape of a ruffle, or flounce — an arrangement which permits the suspension of the very long intestine (20 to 25 ft.) from the comparatively short median dorsal body wall (see Fig. 156). The great arteries and veins lie in the mesentery near the dorsal body wall, and branches are distributed from them to the intestine within this expanding membrane (see Fig. 163).

The kidneys do not lie movably suspended in the abdominal cavity, as do the intestines, but are large organs, one on each side, situated near the spinal column and dorsal to the abdominal cavity from which they are separated by the peritoneum. Arteries and veins are supplied to them from the large median artery and the median vein already referred to (*aorta* and *vena cava*, Fig. 15), and these renal arteries and veins are likewise outside the abdominal cavity.

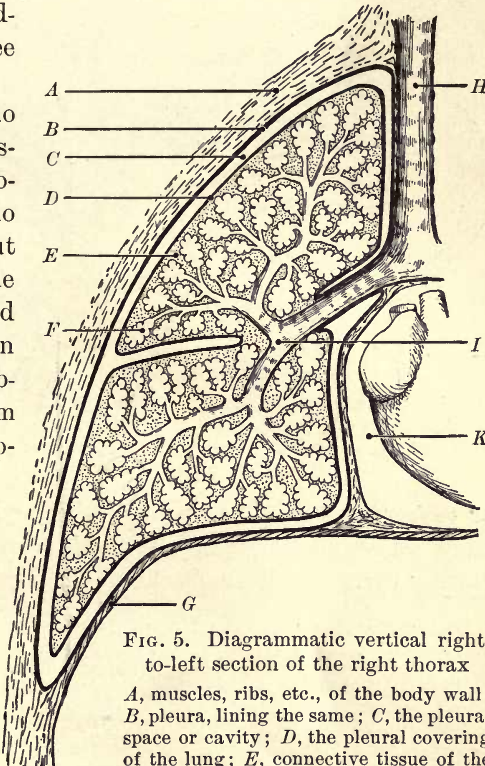


Fig. 5. Diagrammatic vertical right-to-left section of the right thorax

A, muscles, ribs, etc., of the body wall; *B*, pleura, lining the same; *C*, the pleural space or cavity; *D*, the pleural covering of the lung; *E*, connective tissue of the lung; *F*, alveoli of the lung; *G*, diaphragm; *H*, trachea; *I*, right bronchus, branching; *K*, the pericardial space in which lies the heart. Note the division of the lung into two lobes

The relation of the other organs to the peritoneum is more complicated, notably in the case of the liver; but in all cases the organs are inclosed, or wrapped, either in a fold of the peritoneum, as is the kidney, or in a fold of the mesentery, as is the intestine; and their blood and nerve supplies run to them in similar folds.

8. The axial skeleton. The bones and cartilages of which the skeleton is composed may be classified into an *axial skeleton* (of the head, neck, and trunk) and an *appendicular skeleton* (of the arms and legs). The axial skeleton comprises (1) the backbone, or vertebral column, (2) the ribs and breastbone, and (3) the skull.

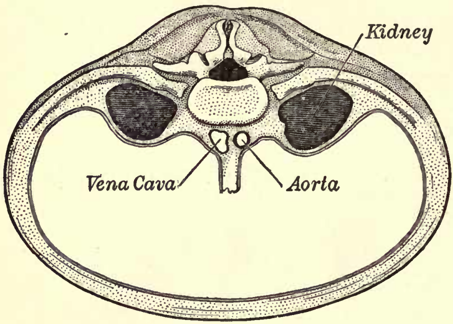


FIG. 6. Diagrammatic cross section of the abdominal cavity

Showing the relation of the kidneys and great blood vessels to the peritoneum. The intestine has been removed, the cut border of the mesentery being shown

9. The backbone, or vertebral (spinal) column. This is composed of separate irregular ringlike bones, or *vertebræ*, placed one above another and bound together by bands of strong connective tissue known as ligaments. It is customary to divide the backbone into the following regions:

Cervical, 7 vertebræ of the neck.
Thoracic, 12 vertebræ of the chest, to which ribs are attached.
Lumbar, 5 vertebræ of the "small of the back."
Sacral, 5 vertebræ (fused together) to which the large hip bones are attached.
Coccygeal, 4 or 5 very small, simple vertebræ (constituting the skeleton of a rudimentary tail and corresponding to the tail of lower animals).

When one looks at the spinal column from behind, the vertebræ are seen to be placed one upon another, but *all in the median dorsoventral plane of the body* (see Fig. 7). Seen from the side, however, several curves come into view, as shown in Fig. 10. On the ventral side, in the cervical and

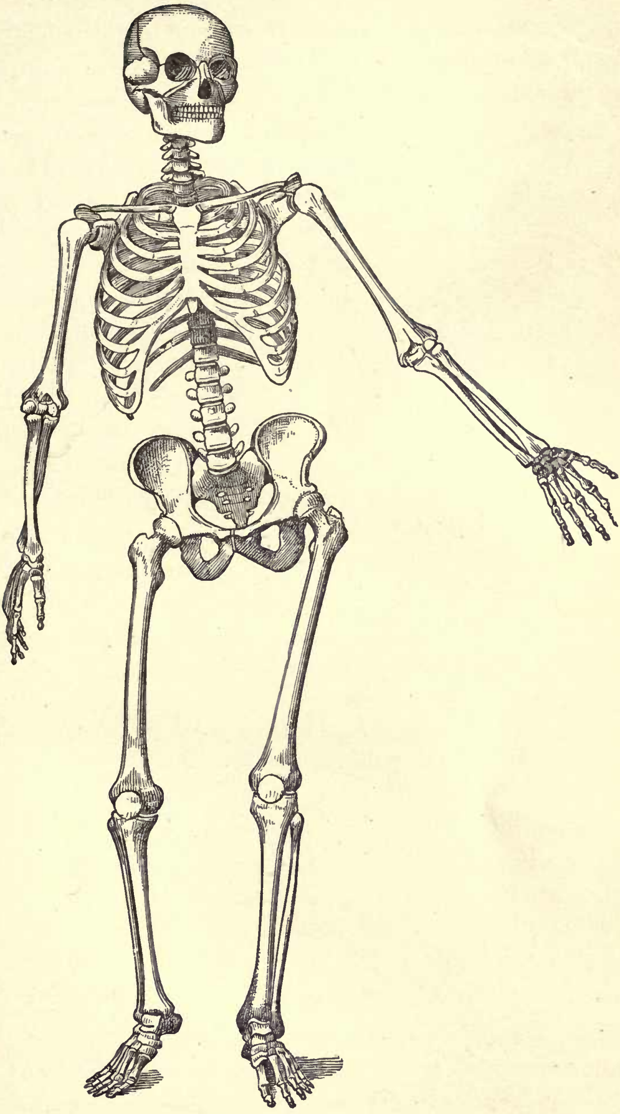


Fig. 7. The skeleton entire

upper thoracic region, the curvature is slightly convex; in the thoracic region it is quite concave; in the lumbar region slightly convex; and in the sacral-coccygeal region again concave. It may well be asked how these separate vertebræ, piled, as it were, one above another, maintain their proper relative positions. This is partly due to the shape of the individual vertebræ, partly to the ligaments (p. 17) which pass from one vertebra to another and limit the movements of each, and partly to the action of muscles which are placed upon opposite sides of the vertebræ and by their *antagonistic* action hold them in place. The action of muscles and ligaments upon the bones may be illustrated by two blocks of wood held together by two rubber bands (m, m', Fig. 11) slightly stretched; so long as each pair of opposite bands pulls with the same force, the blocks are kept in what we may call their resting position. Here the rubber bands represent two of the antagonistic muscles, which, by maintaining a steady and equal pull on the opposite sides of the vertebræ, keep them in place. Should one pull harder than its antagonist, as when a muscle contracts (see Chap. IV), the antagonist will be stretched and the bones become inclined toward one another, as shown in right portion of Fig. 11.

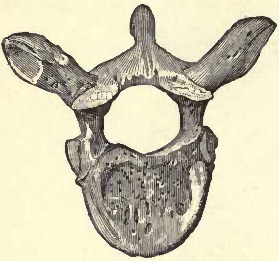


Fig. 8. Sixth thoracic vertebra
Seen from above

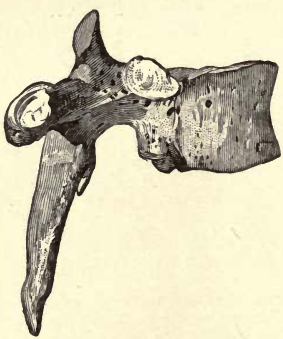


Fig. 9. Sixth thoracic vertebra
Seen from the side

This principle of muscular antagonism is quite general in the maintenance of the proper relative positions of bones in the body. Almost every joint is the theater of such plays of antagonistic muscles, which serve the double function of keeping the bones in proper position with regard to one another and of producing movement at the joint, the amount of this movement being limited by the slack but inextensible connective-tissue ligaments which bind the bones together. In Fig. 11 both the shortening of the muscle and the slackness of the ligaments are purposely exaggerated, in order to represent more clearly the functions of these tissues. Ligaments may also guide the movement of bones by preventing motion in one direction or another.

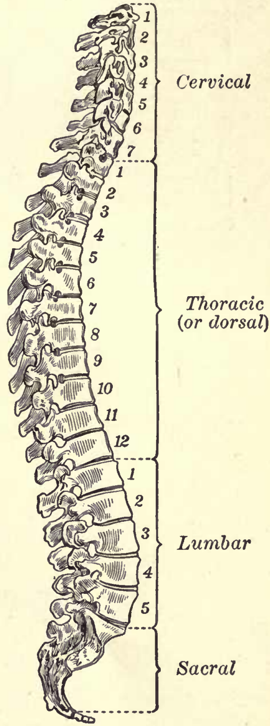


FIG. 10. The vertebral column

Seen from the side

10. The ribs. Each rib consists of a *bony* and a *cartilaginous* portion. The former articulates (that is, forms a joint with) the vertebral column, while the latter continues this bony portion to the ventral median *breastbone*, to which it is directly joined. The ribs form the framework for the thorax and may be lifted or lowered by muscles which connect them with the vertebral column and other parts of the skeleton (see Fig. 12).

11. The skeleton and the central nervous system. The skull consists of the bones of the *face* and those of the *cranium*, the latter holding the brain. It is supported on the spinal, or vertebral, column, whose ringlike vertebræ inclose a bony canal continuous with the cranial cavity. This is known as the *spinal*, or *vertebral*, *canal*, in which lies the spinal cord[1] — the continuation of the central nervous system posterior to the brain.

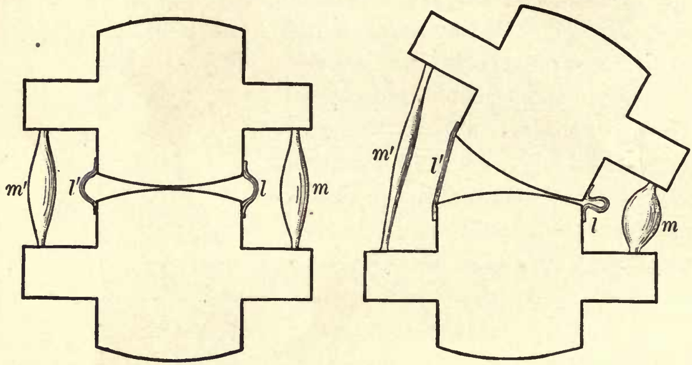


Fig. 11

Model showing the action of muscles on two vertebræ and of the ligaments (*l, l'*) in limiting the amount of movement. The contraction of the muscle *m* stretches its antagonist *m'*. The amount of movement is greatly exaggerated

Nerves, which pass through small openings in the cranium and between the vertebræ, leave the brain and cord and end in the muscles, skin, glands, and other organs of the body (see Chap. VII).

12. The appendicular skeleton. The bones of the arm, leg, hand, and foot may readily be felt and are sufficiently familiar. We may, however, call attention to the similarity in the number and form of the bones of the arms and legs, a similarity which is not only helpful

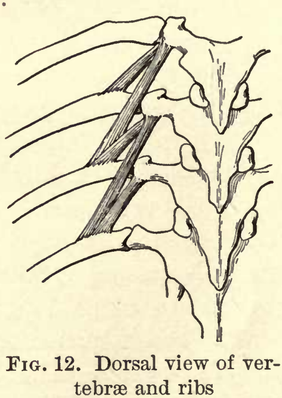


Fig. 12. Dorsal view of vertebræ and ribs

Showing some of the muscles which lift or raise the ribs

[1] The terms "spinal cord," "spinal column," and "spinal canal" are sometimes confused by beginners. The spinal column is the entire bony framework formed by the vertebræ — the whole backbone; it surrounds the spinal canal, which, in turn, contains that part of the nervous system known as the *spinal cord*.

in mastering their names and arrangement but is also suggestive of the similarity of function in quadrupeds, both limbs in these animals being organs of locomotion.

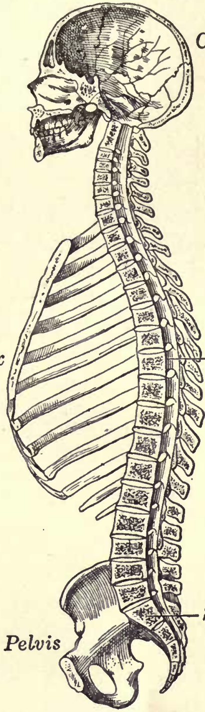


Fig. 13. Median dorsoventral section of the skeleton

ARM

Humerus, single long bone of the upper arm.

Radius and *ulna*, two nearly parallel bones of the forearm.

Eight small irregular bones of the wrist.

Five parallel bones of the palm.

Bones of fingers { Thumb, two bones. Other fingers, three bones.

LEG

Femur, single long bone of the thigh.

Tibia and *fibula*, two nearly parallel bones of the lower leg.

Seven small irregular bones of the ankle and heel.

Five parallel bones of the instep.

Bones of toes { Great toe, two bones. Other toes, three bones.

The legs are attached to the vertebral column by the large *hip bones*, which articulate directly and immovably with the *sacrum*[1]; but the *humerus*, or bone of the upper arm, articulates on each side with one of a pair of bones which form the *shoulder girdle*, or skeleton of the shoulder region; this pair consists of the *collar bone* (*clavicle*) ventrally and the *shoulder blade* (*scapula*) dorsally. The clavicle articulates with the head of the breastbone; otherwise the shoulder girdle, with the arm attached to it, is connected

[1] The sacrum and the two hip bones together form the *pelvis*.

with the axial skeleton by muscles only. A wide range of movement is thus secured at the shoulder joint.

13. Organs of digestion. The digestive system consists essentially of a long tube, the *alimentary canal*, passing through the body.[1] Into this tube, at various points, ducts from a number of glands pour *digestive juices*. The alimentary canal begins with the *mouth cavity* and its familiar organs, the *teeth*, the *tongue*, etc.; this cavity opens posteriorly into that of the *pharynx*, into which also opens the *nasal cavity*, separated from the mouth only by the *palate* (see Fig. 14).

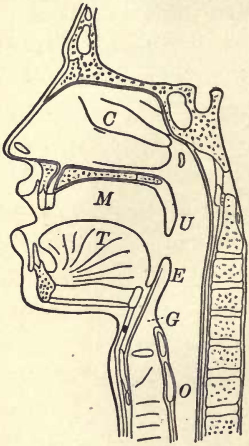


FIG. 14. Diagrammatic median dorsoventral section of the nasal and throat passages

C, nasal cavities; *M*, mouth cavity; *T*, tongue; *E*, epiglottis; *G*, glottis, or opening from the pharynx into the trachea; *U*, the end of the soft palate; *O*, œsophagus

On the ventral side of the pharynx, just beyond the root of the tongue, is the slitlike opening of the windpipe (see sect. 14); posteriorly the pharynx is continued in the long gullet, or *œsophagus*, a tube which passes downward through the neck and thorax (within the mediastinum) to join the stomach, which it enters immediately after passing through the diaphragm.

The *stomach* is a large pouch with contractile walls permitting adaptation of its size to the bulk of food it may contain. Its situation is shown in Fig. 155, which also shows how it opens on the right side of the body into the very long, coiled *small intestine*. The coils of this part of the tube may be followed for from twenty to twenty-four feet, to the large intestine, into one side of which it opens. The *large intestine*, or *colon*, consists of three portions: the first *ascending* on the right side to the general level of the stomach, the

[1] See Fig. 155 for the general arrangement of the organs of digestion.

second passing *transversely* at this level from right to left, and the third *descending* on the left side to the *rectum*, the posterior terminal portion of the digestive tube.

Numerous glands pour secretions through ducts into the digestive tube, the more important, with their places of discharge, being the following: salivary glands (see Chap. III) — mouth; liver — beginning of small intestine; pancreas — beginning of small intestine (see Fig. 54). Smaller glands empty into the stomach and intestines at numerous places.

14. The organs of respiration. The organs of respiration consist of the right and left *lungs* (see Fig. 5), from each of which a single *bronchus* (pl. *bronchi*) leads to the *trachea* (or *windpipe*). The walls of the trachea and bronchi are kept from collapsing by successive rings of cartilage. Anteriorly the trachea opens into the pharynx through the *larynx*, or *voice box*, the cartilages of which may be felt in the throat at the root of the tongue. The familiar hoarseness which accompanies inflammatory roughening of the lining of the larynx shows how important is this organ in the production of the voice. The respiratory and digestive paths cross in the pharynx, the former reaching the exterior through the nose, the latter through the mouth.

15. The organs of circulation. The position of the heart and the great blood vessels in the thorax has been described on page 11. The heart is essentially a large mass of muscle containing a cavity which is divided into right and left halves, wholly separate from each other. The cavity on each side is divided into that of the large *ventricle*, with very thick walls, and that of the much smaller *auricle*. The heart is thus composed of right and left auricles and right and left ventricles. Valves are so placed in the heart as to allow blood to flow in one direction only (see Fig. 69).

The *arteries* are tubes which carry the blood to the tissues, and from each side of the heart a single artery takes its origin — the *pulmonary artery* from the *right* ventricle, and the *aorta* from the *left* ventricle. The pulmonary artery supplies the lungs with blood, while all other organs are supplied by the aorta.

The *veins* are tubes which conduct the blood from the various organs to the heart. Beginning in the tissues as microscopic tubes, they unite to form larger and larger tubes as they approach the heart; those visible through the skin of the hand may be regarded as of medium size; as the union goes on, the size of the vessels increases until finally at the heart there are only two *great veins* on the right side (*superior vena cava* and *inferior vena cava*) and four on the left (*pulmonary veins*). The *venae cavae* bring blood back from those portions of the body which are supplied by the aorta, that is to say, from all parts of the body except the lungs; the pulmonary veins bring blood back only from the lungs, that is to say, from the organs supplied by the pulmonary arteries. The venæ cavæ empty into the right auricle, the pulmonary veins into the left auricle. The general arrangement of heart, arteries, and veins is shown in Fig. 15, and the figures in Chapter IX (especially 70 and 71) should also be consulted.

The blood flows in the following circuit:

Pulmonary circulation
- Right ventricle to
- Pulmonary artery to
- Lungs to
- Pulmonary veins to

Systemic circulation
- Left auricle to
- Left ventricle to
- Aorta and its branches to
- All organs of the body (except the lungs) to
- Veins which unite to form the *venae cavae* to
- Right auricle to
- Right ventricle

Thus the blood which leaves the left ventricle flows to the different organs of the body (except the lungs) and returns by way of the veins to the right side of the heart;

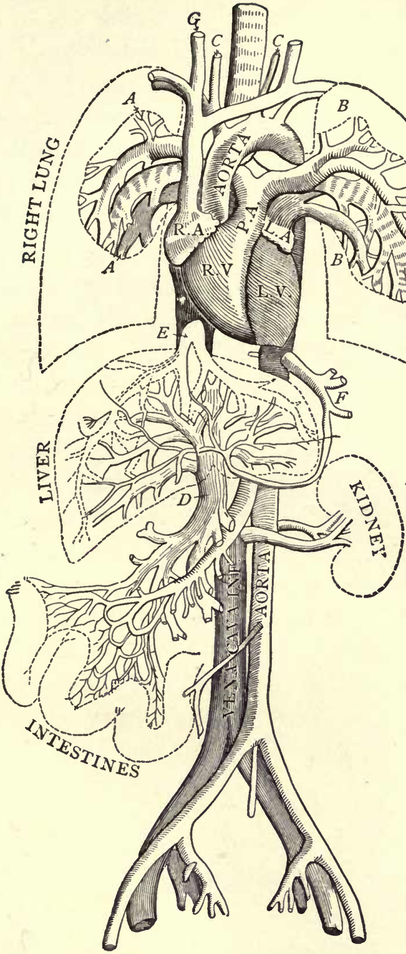


Fig. 15. Diagram of the circulation of blood

R.A., right auricle; L.A., left auricle; R.V., right ventricle; L.V., left ventricle; P.A., pulmonary artery; *A*, pulmonary artery and vein of right lung; *B*, pulmonary artery and vein of left lung; *C*, carotid artery to head, showing branch of left subclavian artery; *D*, portal vein; *E*, hepatic vein; *F*, hepatic artery; *G*, jugular vein, bringing blood from head and neck thence it passes through the lungs and again to the left auricle and ventricle, thus completing the "circulation." The term "circulation," strictly speaking, is applied to the entire circuit which the blood must traverse before it returns again to the point from which it started; it is often convenient, however, to use it to denote the course from the right ventricle to the left auricle, or from the left ventricle to the right auricle; in this case we speak of the former as the *pulmonary* and of the latter as the *systemic*, or *aortic*, circulation. In this sense there may be said to be a "double" circulation.

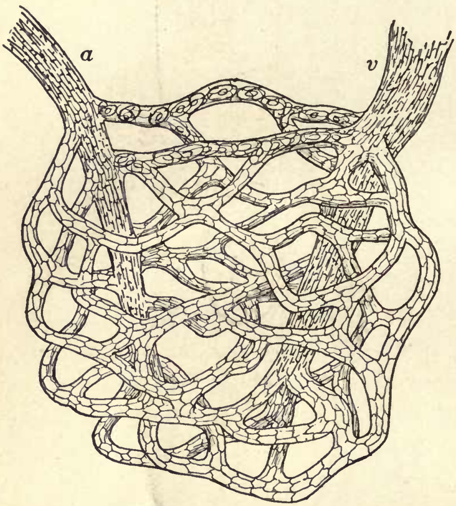


Fig. 16. A network of capillaries, with the artery *a* and vein *v* (highly magnified)

The veins have thinner walls than the corresponding arteries, and those of the systemic circulation contain purplish or even bluish blood, while the arteries of the same circulation contain bright-scarlet blood. The bright color of the arterial blood is due to the fact that it contains more oxygen. The change from purple to scarlet occurs in the lungs, and the reverse change in the organs supplied by branches of the aorta. Consequently the blood of the pulmonary arteries is blue, or venous, in color and that of the pulmonary vein scarlet, or arterial.

16. The course and branches of the pulmonary artery and vein. Soon after leaving the right ventricle the pulmonary artery divides into two branches, one going to each lung.

Each of these further divides as it plunges into the substance of the lung alongside the bronchus. The course of the four pulmonary veins may be similarly traced into the lungs, from which they bring the blood back to the heart (Fig. 15).

17. The course and branches of the aorta. The aorta passes anteriorly from the left ventricle, but very soon arches dorsally and posteriorly, forming the *arch of the aorta* (Fig. 15); the general course of the artery can be best understood from the figures or from actual dissection. The arch of the aorta is continued in the large *dorsal aorta*, which passes posteriorly on the left side of the mediastinum near the spine, through the diaphragm, to the lower portion of the abdominal cavity, where it divides into two large arteries which supply blood to the hips and legs. From the arch of the aorta three large arteries pass to the head, neck, shoulders, and arms; from the thoracic dorsal aorta arise a number of small arteries which supply the muscles and other organs of the thoracic wall; immediately after passing through the diaphragm two large branches go to the stomach, spleen, liver, pancreas, and a large part of the small intestine; posterior to these the *renal arteries* pass right and left to the kidneys, and still further down a large artery supplies the lower small intestine and the

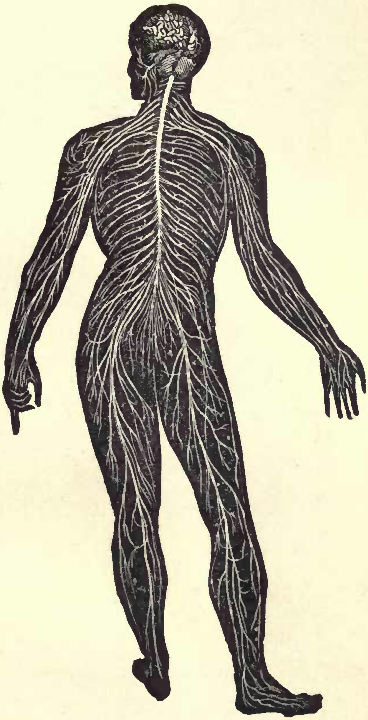


Fig. 17. The general arrangement of the nervous system (dorsal view)

large intestine. The supply to the legs has already been mentioned. Other small arteries arise from the abdominal aorta and are distributed to the muscles and skin of the back. The arteries to the stomach and intestine lie in the mesentery (Fig. 163) and their course may be readily traced in a dissection.

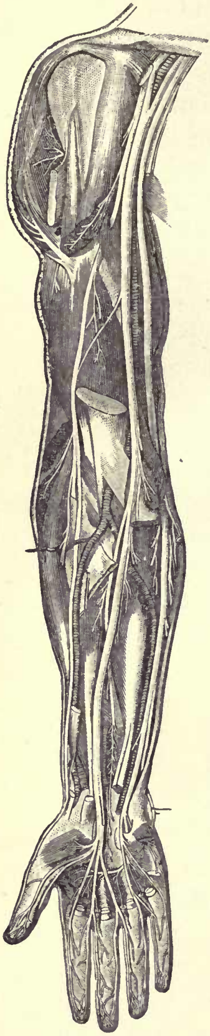


Fig. 18. Nerve trunks of the right arm

18. The course and branches of the venæ cavæ. The blood which has thus been distributed from the aorta returns to the opposite side of the heart through the veins which ultimately form the two venæ cavæ. In general, it may be stated that the veins of those organs which are anterior to the diaphragm form the superior vena cava, while those posterior to the diaphragm form the inferior vena cava. The larger veins usually run near and approximately parallel to the larger arteries. This is the case with those from the arms and legs, the kidneys, and the muscles of the trunk. One notable and very important exception, however, is found in the venous supply of the stomach, spleen, and intestines, the veins of which unite to form a single large vein (*portal vein*) which passes to the liver, where it breaks up into smaller vessels; the blood which has thus passed through the liver is finally collected in the *hepatic vein* and poured by this into the inferior vena cava just before the latter passes through the diaphragm on its way to the right ventricle (Fig. 15; see also Fig. 70).

19. The capillaries. The blood which enters an organ through the arteries passes to its veins through a system of microscopic tubes (Fig. 16), the capillaries (Latin *capilla*, "a hair"); these may be readily seen under the microscope in the web of a frog's foot. From the foregoing description of the course of the circulation it will be observed that generally the blood must pass through one set of capillaries in going from the aorta to the venæ cavæ or from the pulmonary artery to the pulmonary vein; but the blood which flows through the capillaries of most of the abdominal organs (stomach, intestines, spleen) must pass also through a second set of capillaries, namely, those of the liver, before it can return to the heart.

20. Organs of the nervous system. The skull and the spinal column (p. 18) are chiefly occupied by the *brain* and the *spinal cord*, respectively, and from each of these principal organs of the nervous system branches consisting of cords of nervous substance, the *nerves*, pass out through small holes in the skull or spinal column and are distributed to all the other organs, where they terminate in peculiar structures called *end organs.* The optic nerve, for example, ends in the retina, the auditory nerve in the inner ear, and motor nerves in muscles — the nerve endings in these different organs differing materially in structure and arrangement.

Fig. 17 gives some idea of the general arrangement of the nervous system. The nerves to the shoulder, arm, and hand will be seen to arise from the cervical region of the spinal cord; those for the trunk, from the dorsal and lumbar regions; those for the legs, from the sacral region. The head and face receive nerves from the posterior portions of the brain. The dissection of the arm in Fig. 18 shows more accurately the main nerve trunks to that region. Further information with regard to the structure of the nervous system will be given in Chapters VII, XIV, and XV.

CHAPTER III

THE FINER STRUCTURE OF TWO TYPICAL ORGANS, GLANDS AND MUSCLES. THE CONNECTIVE TISSUES. THE LYMPHATIC SYSTEM

In the previous chapter we have examined the general construction of the human machine as regards its more conspicuous parts or organs, and especially their location,—whether internal or external, dorsal or ventral, anterior or posterior, on the right or on the left,—their relations to certain important cavities, and their combination to constitute the mechanism which we call the human body. We must now push our examination further and investigate the finer structure of some of the more important parts of the machine. For this purpose we may select two typical organs, a gland and a muscle, the one unfamiliar, by name at least, to most people, the other well known in the form of steaks, chops, roast beef, and other meats.

1. What is a gland? A gland is a mass of tissue, generally softer than muscle and of no special size or shape, though often rounded or egg-shaped. The gland most easily seen is the milk gland or udder of the cow. This is a large mass of soft tissues devoted to manufacturing or *secreting* milk. In general, glands are manufacturing organs for the preparation of saliva, gastric juice, bile, tears, sweat, or other secretions. Some have tubes, or *ducts*, through which their secretions are carried away; others have no such outlets and hence are known as *ductless* glands. Glands vary in size from some which are microscopic to the huge liver, which is the largest single organ in the human body (see Fig. 2). The *pancreas*, or "sweetbread," of the calf is an excellent gland for the beginner to dissect or study.

2. A typical gland. If we have before us the whole or a part of any typical gland, we find that we are dealing with a comparatively soft and sometimes even pulpy mass held together by a loose mesh or network of harder, tougher, and more or less fibrous materials. A pancreas or a liver, if entire, shows conspicuous *lobes*, and in the pancreas these lobes are plainly subdivided into smaller lobes, or *lobules*. In favorable specimens tubes may be seen connected with the gland; some of these are blood vessels supplying blood to the gland, and one of them is a duct draining away from it the liquid which the gland has manufactured or secreted. After a preliminary examination of this sort of some edible gland, preferably the pancreas, we may pass on to consider in greater detail one of our own *salivary* glands, of which we have two on each side of the head, namely, one *parotid* and one *submaxillary* gland.

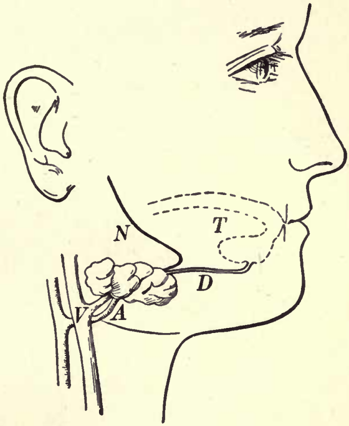


FIG. 19. Diagram of submaxillary gland

D, its duct; *N*, its nerve; *A*, its artery; *V*, its vein; *T*, tongue

3. The structure of the submaxillary gland. The two submaxillary glands lie, one on each side of the face, embedded in the tissues between the lower jaw and the upper portion of the neck. From each gland a duct passes forward in the tissues forming the floor of the mouth, into which it opens by one of the small eminences, or *papillæ*, under the tongue. Through this duct the gland pours into the mouth its secretion, *saliva*.

If the gland were to be cut in two in any direction with a sharp knife, we should see at once that it is composed of separate parts, or *lobes*, and that these lobes are still further divided into smaller portions, or *lobules*. The lobules and lobes are bound together with a rather loose connective tissue which is continuous with a somewhat denser layer surrounding the gland and forming its *capsule*; the connective tissue between the lobes forms the *primary septa* (sing., *septum*) and that between the lobules the *secondary septa*. The relation of these structures is shown in Fig. 20. With the aid of the microscope we find that each lobule is still further divided by connective tissue into flask-shaped structures, or *alveoli* (sing., *alveolus*); in these the secretion, saliva, is manufactured and from them it is discharged into the duct of which the alveoli are the blind ends (Fig. 21).

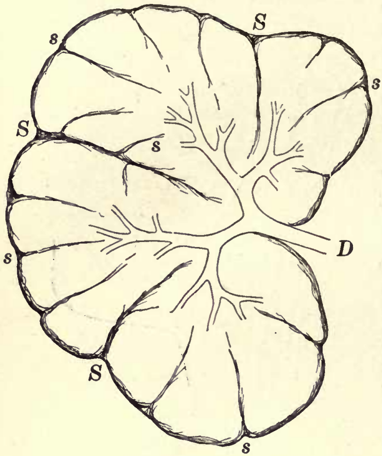


FIG. 20. Diagram of a cross section of a gland

Showing its division by primary septa (*S*) into lobes and by secondary septa (*s*) into lobules; also the origin of the larger branches of the duct (*D*) in the lobes and lobules. The beginnings of the duct are shown in Figs. 21 and 22

The whole gland may be compared to a large bunch of grapes; the main tubular duct of the gland branches (in the septa of connective tissue) very much as the stem of the bunch of grapes branches; and just as the branches and subbranches of the stem lead, when followed up, to the grapes themselves, so the branches of the duct lead to the alveoli of the gland. If now we pack the bunch of grapes in a small basket of sawdust or cork waste, as Malaga grapes are packed, so that the sawdust fills up loosely the spaces between the individual grapes and the branches of the stem, we shall have something with which to compare the arrangement of the connective tissue in relation to the rest of the gland — the sawdust standing for the connective tissue in which the ducts and alveoli are embedded, and the basket for the capsule.

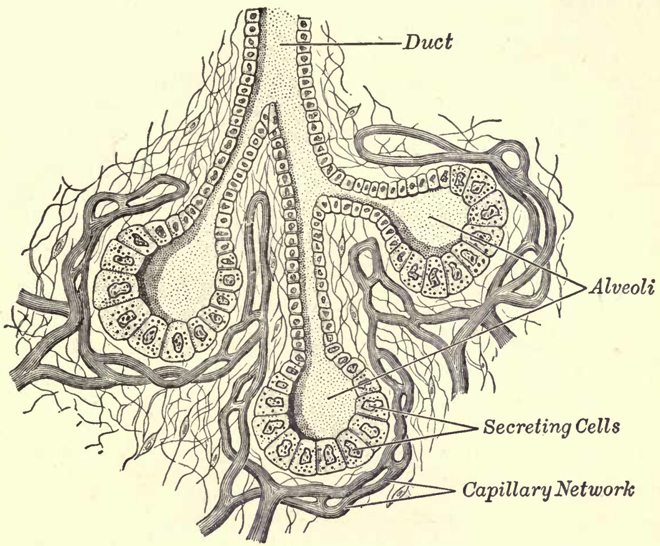


FIG. 21. The origin of the duct of a gland in alveoli, together with the connective tissue and blood vessels

4. Minute structure of ducts and alveoli. The alveoli are not, however, empty shells like glass flasks nor solid masses like grapes, but rather hollow bags lined with a layer of thickish, closely set *cells*, all much alike. Each of these cells consists of two portions — a small central body, the *nucleus*, and a larger surrounding mass, the *cytoplasm*. All organs of the body are composed of cells, differing in different organs or in different parts of the same organ (as in the duct and the alveolus of the gland), but *all consisting of two never-failing parts — nucleus and cytoplasm.*

The muscle and the gland consist of cells, just as all the branches of the military service — the infantry, the cavalry, the artillery, the engineers, etc. — consist of men. The cell is the anatomical or fundamental unit of these organs, as the soldier is the fundamental or anatomical unit of the army; in both cases the anatomical units, differing in equipment and training, perform different kinds of work, yet have the

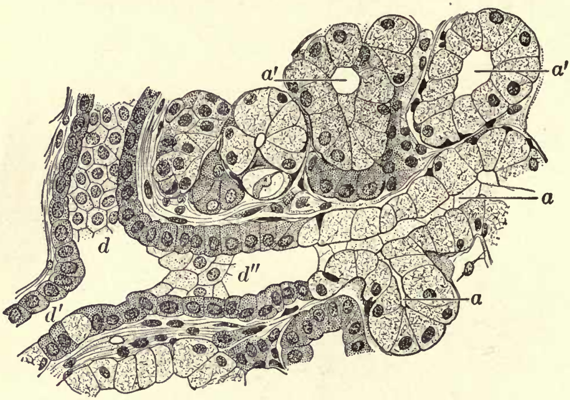


FIG. 22. Section of a portion of a salivary gland (magnified 500 diameters) After Kœlliker

The duct *d* divides into the two branches *d'* and *d''*, one of which ends in the alveoli, *a*, *a*. Neighboring alveoli, *a'*, *a'*, whose ducts are not in the plane of the section, are also shown. In some cells the section does not include the nucleus, which would be in the preceding or the succeeding section

same essential structure; and the cells are combined into brigades, divisions, or corps, as tissues and organs; they make of the body an army organized to fight its way through the vicissitudes and against the obstacles of life.

5. The structure of the biceps muscle. The biceps muscle is familiar as the mass of flesh lying on the front of the upper arm and bulging somewhat when the arm is bent at the elbow, especially when one "feels his muscle" or when a weight is being lifted by the hand. Figure 23 shows this muscle with the bones to which it is attached. It consists of two portions: a central, thick, red part, known as the *belly*, soft when the muscle is at rest, hard when it is contracted; and cordlike strings, or *tendons*, two at the upper end and one at the lower, by means of which the muscle is attached to two bones of the shoulder girdle and to one of the forearm. When the belly of the muscle shortens, the points *a* and *b* are brought closer together and the arm is bent, or flexed, at the elbow. This drawing together, or *contraction*, is the special work, or *function*, of muscles in general.

Everyone has seen the cross section of a muscle in a raw beefsteak. This shows that the muscle as a whole is surrounded by a sheath of connective tissue which contains more or less fat; *septa* pass inwards, dividing the muscle into lesser red masses known as *fasciculi*, or bundles, and these are further subdivided into secondary fasciculi by secondary septa, very much as the gland is subdivided into lobules.

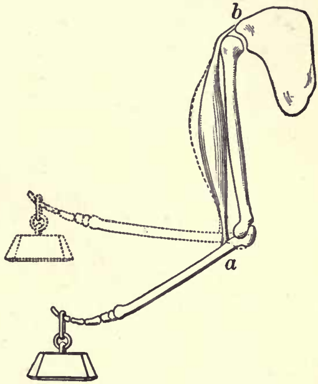


FIG. 23. The biceps muscle of the arm

The resting condition is shown by the solid lines, the contracting condition by the dotted lines

A longitudinal section shows that the fasciculi run from tendon to tendon, and microscopic examination proves that the general connective tissues of the belly of the muscle are continuous with that of the tendon. The tendon itself is a peculiarly strong and inextensible variety of connective tissue consisting chiefly of parallel fibers which are specially fitted to transmit to the bone the pull of the belly of the muscle.

6. The muscle fibers. Examination of the structure of one of the finer fasciculi in the belly of the muscle shows that it is composed of threads, or fibers, which at first sight differ greatly from the secreting cells of the gland. These are the *muscle fibers.* They are 1 to $1\frac{1}{2}$ inches in length and from $\frac{1}{2500}$ to $\frac{1}{250}$ of an inch in thickness, thus being from 250 to 2500 times as long as wide, and comparable in shape to a long leather shoe-string rather than to a sausage. Each fasciculus contains hundreds or even thousands of fibers. The fibers always run lengthwise of the fasciculus, but, as a usual thing, do not extend its entire length, as obviously follows from the fact that a single fasciculus of the biceps is several inches in length. The fibers are inclosed in a very thin transparent membrane, the *sarcolemma*, and are bound into bundles (or fasciculi) by the same fine connective tissues seen between the alveoli of a gland. To the end of the sarcolemma are attached fine fibers of connective tissue which pass into the tendon (Fig. 25). Indeed, the fibers of the tendon are the collected fibers from the sarcolemmas of all the muscle fibers. For this reason the part of the muscle near the tendon is "tough meat," while that in the belly of the muscle is tender, owing to the smaller number of connective-tissue fibers.

FIG. 24. Tendon (highly magnified)
Showing the fiber bundles separated

7. The muscle fiber a cell. The muscle fiber at first sight does not seem like the typical cell already described, with nucleus and cytoplasm; for when examined in the fresh condition the only obvious points of structure seen in it are striking *cross striations* consisting of alternate dark and light bands. It has been shown, however, by ingenious and careful study that the cross striations are optical appearances produced by the peculiar shape of extremely minute longitudinal rods in the

FIG. 25. One end of a muscle fiber
Showing the attachment of the tendon fibers to the sarcolemma

cytoplasm of the muscle fiber and that, immediately under the sarcolemma, there are numerous characteristic nuclei which are easily brought into view by suitable treatment. Briefly, then, the muscle fiber is *a cell with many nuclei*, in whose cytoplasm are found peculiar structures, the *myofibrils*; upon superficial examination these myofibrils not only obscure the nuclei but give to the whole fiber the appearance of cross striation.

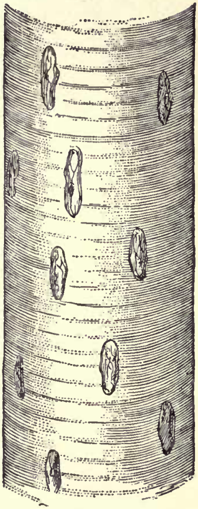
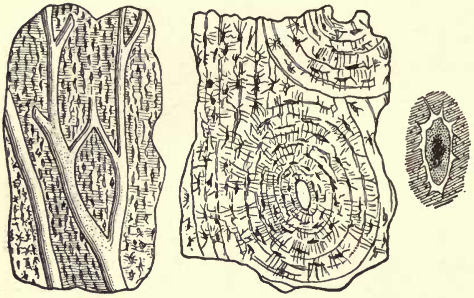


FIG. 26. Part of a muscle fiber

Specially prepared to bring out the numerous nuclei

8. How far is the structure of glands and muscles typical of all organs? Both the gland and the muscle are thus composed of *cells.* Although differing considerably in the two organs, these cells possess certain general and fundamental features in common, for each one contains a nucleus (or nuclei) and surrounding cytoplasm. Is the same thing true of all other organs? The muscle and the gland are examples of organs which do active work, but some other organs perform purely passive functions. Such are the bones, which do no work themselves, but upon which the work of mechanical motion is done by the muscles; the tendons, which transmit the pull of muscles; the ligaments, which limit and sometimes guide the motion of bones; and the connective tissues, which bind together other parts of the body. None of these is a working organ in the sense that a muscle or a gland is a working organ, and we are not surprised to find that their structure departs from that of the muscle and gland in that, while nucleated cells are present in all of them, *the great mass of the organ is composed of lifeless matter between the cells.* In a tendon this consists of very strong parallel fibers (Fig. 24); a ligament shows much the same structure; a bone consists chiefly of lifeless material containing large amounts of mineral matter, with cells lying here and there in spaces which communicate with one another by means of minute channels. The connective tissues, like that which binds the skin to the underlying muscles or that which forms the sheath and septa of glands and muscles, consist essentially of lifeless fibers running in all directions and thus ready to limit the extent of any pull tending to separate unduly the adjacent organs. To organs and tissues of this kind we may give the name of *supporting organs and tissues*, and they form almost the sole exception to the general rule that the essential part of a tissue consists of its cells. The latter statement is true of all organs and tissues which do work — the active organs of the body. In the case of the supporting tissues the cells which they contain are the fundamental units of the organ, since they make the intercellular lifeless substance; but the part which the organ plays in the work of the body as a whole is performed by the lifeless substance (fibers, etc.) which the cells have manufactured and keep in repair.



A *B* *C*

FIG. 27. Longitudinal (*A*) and transverse (*B*) sections of bone

Showing the branching and communicating canals — in which are blood vessels and nerves — surrounded by the lifeless bone substance. In this are spaces connected with one another by very minute channels. Each of these spaces contains a living cell, shown in *C*

9. The blood vessels are closed tubes in connective tissue. The arrangement of connective tissues is fundamentally the same in gland and muscle. These tissues serve the obvious purpose of binding the anatomical units into organs, but they also perform other functions equally important.

We have seen (Chap. II, sect. 19) that each organ receives blood through one or more arteries, and that this blood flows away from the organ through one or more veins. If a colored fluid mass which would afterwards set (for example, a warm solution of gelatin colored with carmine) had been forced into the arteries before we began our examination, we should find that this mass would everywhere be confined in a system of closed tubes which merely lie in the connective tissue. The artery entering the muscle branches into smaller and smaller arteries in the general sheath of the organ, or in its branches, the septa; from these finer arteries an exceedingly rich network of small thin-walled tubes is given off to the finest connective tissue which surrounds the cells themselves; these tubes are the *capillaries*. They ultimately unite to form the larger veins, which can be traced in the septa to those veins which gross dissection reveals as leaving the organ (see Fig. 19). Through these tubes—arteries, capillaries, and veins — the blood flows; and it is important for us to understand that it is everywhere *confined to them* in its passage through the organs; *nowhere does it come into direct contact with the living cells* (save those lining the vessels). Whatever exchange of matter or energy takes place between the blood and the living cells must be through the walls of the blood vessels.[1]

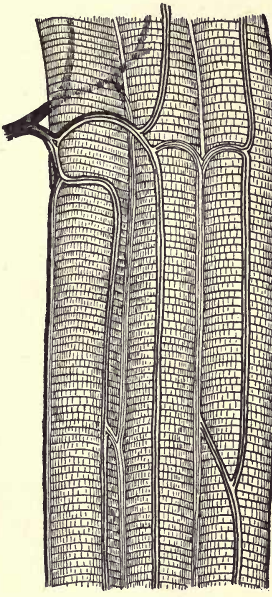


FIG. 28. Three muscle fibers and an artery breaking up into capillaries between them

[1] The term "blood vessel" is sometimes confusing to the beginner, since it suggests a utensil for holding liquids. In anatomy "vessel" is a name for *tubes*, *ducts*, or *canals* through which blood or lymph flows.

These walls are relatively thick in the arteries, usually somewhat thinner in the veins; in the capillaries, however, they are very thin, and it is through these thin capillary walls that all interchanges of matter take place. That the connective tissue surrounding the capillaries bears an important relation to the circulation we shall now see.

10. The lymph spaces of the connective tissue; the lymph. Careful examination shows that the fine connective tissue within which the capillaries are embedded is not a solid or continuous mass, but rather a mass or mesh of extremely fine fibers or bundles of fibers, with here and there connective-tissue cells which keep the fibers in repair. The connective tissue, therefore, is everywhere channeled by irregular spaces running between the fibers and other structures; these spaces communicate freely with each other and contain a colorless liquid known as *lymph*; the spaces of the connective tissue may thus be conveniently described as *lymph spaces*. They serve as communicating channels between the cells and the walls of the capillaries.

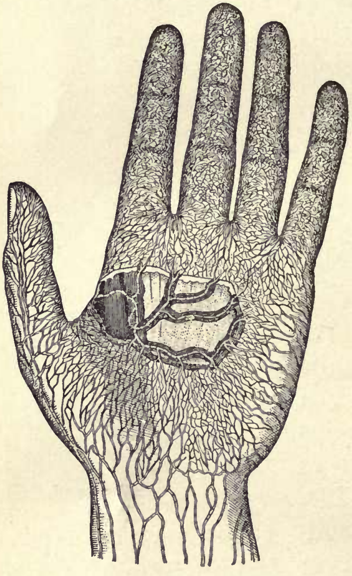


FIG. 29. Superficial and some deeper lymphatics of the hand

11. Origin of the lymph. The lymph which the spaces contain is derived partly from water and soluble food materials which have passed through the capillary walls from the blood and partly from material produced by the neighboring cells (see the next chapter); on the other hand, the cells absorb from the lymph substances which the latter has received from the blood, while the blood, in turn, takes from the lymph substances discharged from the cells. The lymph thus becomes the means of communication, the middleman, between the living cells of the organs and the nourishing blood, and forms the immediate environment of the cells themselves. In other words, *the cells of muscles, glands, and other organs live in lymph*, just as the human body as a whole lives in air, or a fish in water.

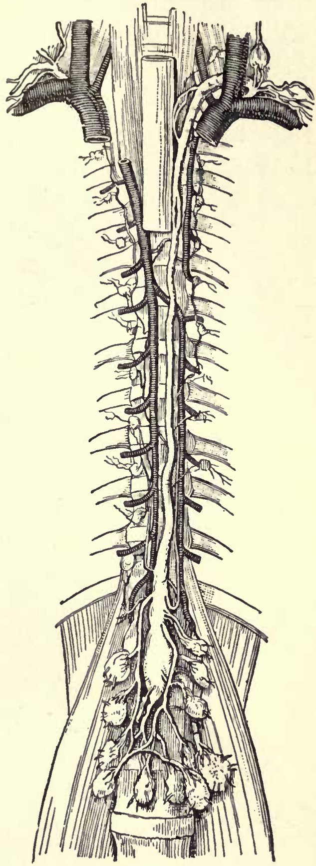


FIG. 30. The two main lymphatic trunks (in white), with their openings into the great veins near the heart

The larger of these trunks — that on the left side and known as the *thoracic duct* — returns all the lymph except that from the right side of the head and neck and the right arm and shoulder region

12. The lymphatics. Besides the veins, which convey blood away from an organ, a second system of tubes or vessels passes out through the capsule. These tubes arise in the lymph spaces of the connective tissue and unite with similar tubes from other regions to form larger and larger trunks, known as *lymphatics*, which ultimately form one or two great trunks and open into the great veins near the heart (see Fig. 30). Through these direct outlets the surplus lymph of the organ flows in a varying but for the most part continuous stream. This flow of lymph away from an organ is of the very greatest importance in maintaining the normal environment of the cells.

13. Function of the lymph flow from an organ. It is clear from inspection of Fig. 31 that there is a steady flow of liquid from the capillaries, through the lymph spaces of the connective tissue, over the surfaces of the living cells or of any intervening capillaries, to the lymphatics. The cell is thus bathed not by a stagnant medium but by one which is in gentle movement — one which brings to all parts of its

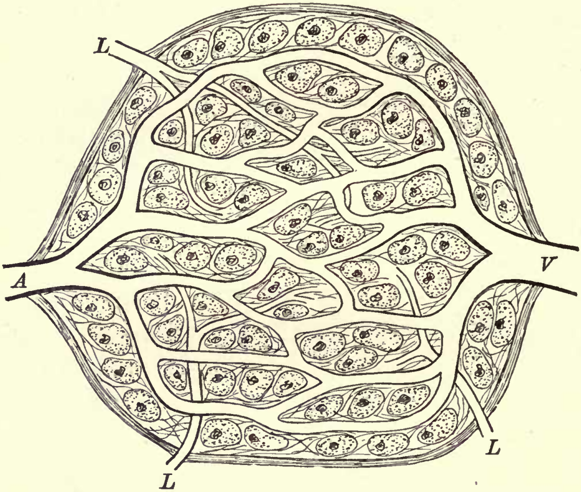


Fig. 31. Diagram of the relation of the cells of an organ to its blood vessels, lymphatics, and connective tissue

A, artery; *V*, vein; *L*, lymphatic

surface the food which it needs and immediately carries away from all parts of its surface to the adjacent capillaries the products of its activity. By providing this outlet from the lymph spaces the lymphatics render possible the movement of lymph within the organ itself, whereby material is readily transferred from the cell to the capillaries and from the capillaries to the cell.

14. Distribution of nerves to muscles and glands. The distribution of nerves resembles that of the arteries, the larger nerve trunks being found in the septa, and their fine ultimate branches being distributed by way of the connective tissue which surrounds the cells, in whose neighborhood or even within whose substance they finally end. As we shall see in subsequent chapters, it is the function of the nerves to arouse the gland cells or muscle fibers or other cells to activity.

15. Summary. Disregarding for the moment those peculiarities of arrangement, shape, and structure of the cells which are connected with the special work of each organ (for example, the arrangement of gland cells to form a blind tube or of the connective tissue and fibers of muscle so as to exert a pull on a bone), we may say that the typical structure of an organ would be represented in Fig. 31. The whole is surrounded by a capsule, receives a blood supply through a system of closed tubes, and contains the special cells upon whose activity its characteristic work depends. These cells are held together by a fine connective tissue whose numerous and freely communicating spaces contain a fluid, the lymph, which is free to flow out through a second system of tubes, the lymphatics. Nerves from the brain or spinal cord are also distributed in the connective tissue to the cells of the organ.

Before concluding this description of the finer structure of organs, a word may be added with regard to the physical nature of the cell substance. In its literal meaning the word "cell" is a misnomer, since it suggests a hollow space inclosed by solid partitions or walls. Plant cells do, in fact, usually have such walls around their cytoplasm (Chap. VIII), and this cytoplasm frequently contains spaces (vacuoles) filled with a solution of salts, sugar, and other dissolved material; but neither the cell wall nor vacuoles are of universal occurrence, each being rarely found in the animal cell, and often absent even in the plant cell. Fifty years of thorough investigation has reduced the number of essential cell constituents to the cytoplasm and the nucleus, the ultimate structure of which is far from being completely understood. It would seem that the cytoplasm is a mixture of a number of materials which differ in chemical composition and in physical properties. Some are dissolved in water, making viscous solutions comparable to the white of egg or to thick or thin jellies. Others are known as *lipins*, or *lipoids* (from the Greek *lipos*, "a fat"), because they resemble fats or oils in physical characters and to some extent in chemical structure; they do not mix, or mix only imperfectly, with the viscous aqueous (that is, watery) solutions, but spread over the outer surface of the cell, forming a membrane, and probably also penetrate into the cytoplasm somewhat as the connective-tissue septa of the gland penetrate the gland. These lipoid membranes would thus separate the viscous aqueous solutions of the cytoplasm into separate masses, much as the gland is divided by its septa into lobes and lobules. The lipins are supposed, among other functions, to control the passage of material into and out of the cell. The cytoplasm also frequently contains granules, one kind of which we have already seen in the zymogen granules of the gland cells.

The nucleus, on the other hand, is known to contain certain other compounds peculiar to itself. Some of these at times are probably in an almost solid state and appear as denser material within the membrane which usually bounds the nucleus; at other times they undergo solution, doubtless as the result of chemical changes taking place within them. There are many strong reasons for thinking that the nucleus bears an important relation to the oxidations of the cell.

CHAPTER IV

THE ORGANS AND CELLS OF THE BODY AT WORK

The understanding of a mechanism involves more than a knowledge of its structure; we must study the mechanism at work, and the human mechanism, which we are studying, may be regarded as a factory in which work is done.

The work of some manufacturing establishments consists in separating useful constituents of the raw material from useless constituents, as where kerosene is refined from crude petroleum; that of others consists in producing chemical changes in the raw material, as where soap is made from fat or oil; while that of a third class consists in the application of power by machinery, as where lumber is sawed, planed, turned, or molded into the material of which houses are constructed. The work of a factory, in other words, is either a *process of refinement* or the *production of a new substance* or the *application of power.*

The human body is a factory which presents in its activities examples of all three of these processes. A large part of digestion is a process of food refinement; out of the food we eat the very substance of the body itself is formed; while all muscular work, including the beat of the heart, consists in the application of power to accomplish useful ends. This work is done chiefly by the two kinds of organs whose structure we have just studied, namely glands and muscles; and just as their structure presents a fundamental similarity of plan, so there is a fundamental similarity in the nature of their activities. This can best be made clear by a somewhat detailed study of each organ at work.

1. Physiology of the salivary glands; working glands and resting glands. The function of the salivary glands is the secretion or manufacture of saliva for use in the mouth, and one of the first things we notice about this act of secretion is that it is not constant but *intermittent.* Most organs have periods of activity, or *work*, followed by periods of inactivity, or *rest*, and these glands are no exception. Physiologists frequently speak of "working glands" and "resting glands." We all know that our own salivary glands work more effectively at some times than at others. The mouth "waters" at the sight of food; when we are in the dentist's chair the flow of saliva often seems excessive, and at other times our mouths are "parched" or "dry."

2. The chemical composition of saliva. The saliva is sometimes thin and flows readily, while at other times it is thick and viscous, or glairy. This difference is caused by the fact that the amount of water in it varies under different conditions. At all times, however, it is a fluid which consists of water containing certain solids in solution. The amount of these solids varies from five to ten parts in a thousand of saliva, and they consist chiefly of three groups of compounds. The first is *mucin*, familiar to us as the chief constituent of the phlegm or mucus discharged from the nose and throat, and giving to the fluid its viscous character; the second group consists of substances known as *enzymes*, those in the saliva having the power of changing starch to sugar; these we shall study in detail in the chapters on digestion; the third group consists of mineral or *inorganic salts*, of which ordinary table salt, or sodium chloride, is the most important. As we shall see, the salts and water are derived directly from the blood, while the mucin and enzymes are *manufactured by the gland.*

3. Blood supply of the working gland. Whenever a gland is actively working there is an increased flow of blood through it. For this reason the resting gland is slightly pink, while the working gland becomes distinctly red. Since the secretion of saliva requires water and this can be obtained only from the blood, it is easy to see why an abundant blood supply is essential to activity. Other constituents of the saliva, such as the inorganic salts, likewise come directly from the blood.

4. The relation of nerves to gland work; irritability. Nerves pass, as we have seen (p. 29), from the central nervous system to the salivary glands. These nerves are essentially bundles of nerve fibers which are distributed from the brain and spinal cord to the neighborhood of the gland cells. Such fibers are the means of conveying to the gland an influence, called a nervous impulse, and nervous impulses cause the gland to secrete. It is also a fact that when these nerves are cut or injured in any way, so that the gland is no longer in nervous connection with the brain and spinal cord, saliva is not secreted, even when food is placed in the mouth. Evidently the activity of the gland is normally aroused by nervous impulses from the brain and spinal cord, just as the activity of a receiving instrument in a telegraph office is aroused by the electric current which comes to it over a wire, or as a mine is exploded by the same means. The gland then stands ready for the act of secretion and is thrown into activity by a nervous impulse from the central nervous system. We speak of this action of a nerve upon the organ in which its fibers end as *stimulation* and that property of an organ in virtue of which it may be aroused by a stimulus as *irritability.*

All the working organs of the body (in contradistinction to the supporting organs, p. 35) are in this sense irritable, and most of them receive nerves which set them to work. Irritable tissues may, however, be stimulated by other means than by nervous impulses. Of these means an electric shock is the most familiar; others are the sudden application of heat, the presence of certain substances in the blood, and even a sharp blow.

We have now to inquire what it is that happens in the gland when it is stimulated by a nervous impulse.

5. The response of the gland to stimulation by its nerve. The visible result of stimulation of the gland is the discharge of saliva into the mouth. Something must have happened in the gland which has led to the passage of water and other substances from the blood (and lymph) through the gland cells into the duct. But something more has happened, for saliva contains several substances which are not found in the blood. The gland has evidently contributed something to the saliva. How were these contributions to the secretion made?

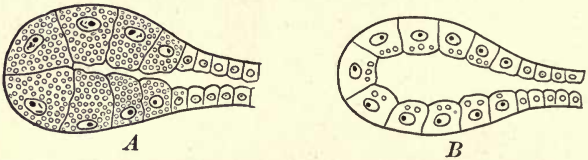


FIG. 32. Diagram showing the granules in a resting gland (*A*) and in a worked alveolus of a gland (*B*)

When a gland has been resting for some time microscopic study shows that the cytoplasm of its cells becomes loaded with small granules, at times so numerous as to obscure the nucleus itself. As secretion goes on these granules disappear from the cell, presumably contributing something to the secretion. If the secretion continue for several hours, it is found that the granules have disappeared and that the cell is often distinctly smaller in size than before secretion began.

The "resting" gland is therefore by no means an idle gland, but gradually stores within its cytoplasm something in the form of granules, which under the influence of nervous impulses or other forms of stimulation more or less rapidly disappears in the secretion.

6. Activity of the gland involves chemical change within its cells. It might be supposed that the granules manufactured during rest are merely dissolved or washed out of the cells in the copious stream of water and salts which during secretion passes through from the blood and lymph to the duct. If this were so, it would be possible to dissolve from the gland a substance exhibiting in general the same properties as the secretion itself. But this is not generally the case. Extracts of fresh glands commonly fail to exhibit the characteristic properties of normal secretions, although these extracts may often be changed by chemical means into the elements of the secretion. We are therefore compelled to believe that the activity of a gland means something more than the mere discharge of previously stored substances; that is to say, the material of the granules in the resting cells is not simply set free when the gland secretes, but is at the same time chemically changed. In the digestive juices, for example, we have active substances called enzymes, which, it has been shown, are derived from other substances, called *zymogens*, in the gland cells. The chemical change from the one into the other is as essential to the process of secretion as is the visible flow from the duct.

These facts then present to us the picture of the cell as the working or physiological unit, as we have already seen that it is the anatomical unit of the gland (p. 32). The work of the gland is the sum of the work of its constituent cells. During the period of rest these cells manufacture from the blood zymogens or other substances which they store away in the form of granules within their cytoplasm. When they are stimulated by the nervous impulse a chemical change takes place in them, the zymogens are changed to enzymes and other substances, and these, together with the water, salts, etc., derived from the blood, form the secretion.

7. Physiology of muscular contraction. At first sight muscles and glands seem to differ in action or function no less than in form and structure. No two acts are apparently more unlike than lifting a weight by the muscles of the arm and the secretion of saliva by the salivary glands. But beneath obvious and important differences there are profound and fundamental similarities in the processes which occur in the two organs during activity. Like the gland, the muscle is set to work or stimulated by a nervous impulse; its contraction is accompanied by an increased blood supply; and, most important of all, the work, or contraction, is accompanied — indeed, *preceded* — by chemical changes much more profound than that of the transformation of zymogen into enzyme. These chemical changes supply the power for the work.

That some chemical change has taken place when the muscle contracts is proved by the fact that certain new substances then make their appearance in the muscle and are given off to the blood flowing through it. The most important of these are *carbon dioxide*, the gas which is formed whenever wood or coal is burned, and an acid substance known as *lactic acid.* These substances were not present in the resting muscle, or else were present in very small quantities. With the act of contraction relatively large quantities of them make their appearance. They are generally spoken of as waste products, and it is known that they are the result of a chemical change in the muscle fiber, or cell, precisely as the enzymes are the result of chemical changes in gland cells. Just as glandular activity produces an output called a secretion, so muscular activity produces an output consisting of substances usually described as *waste products.*

8. The storage of fuel within the muscle fiber. The source of the carbon dioxide and lactic acid produced by the active muscle must in the long run be the matter taken into the body in the form of food. After undergoing in the stomach and intestine relatively simple changes, which do not profoundly affect its chemical constitution, this food is absorbed into the blood and through this channel delivered to the cells. Thus far, however, the food material does not differ greatly from the food as swallowed. Especially to be noted is the fact that it does not undergo sudden and profound chemical change. When, on the other hand, a muscle is stimulated to contraction, there occurs in it a chemical change requiring less than the hundredth of a second for its completion. This of course suggests the chemical change in gunpowder or dynamite. Obviously the food delivered by the blood to the muscle fiber has been transformed in the fiber into something more unstable, something capable of a very sudden chemical change. The meat, bread, butter, potatoes, and the like have been changed into something comparable to the phosphorus in a match or the gunpowder in a percussion shell. This unstable material has not been demonstrated as granules or other visible material within the cell, as have the zymogen granules of a gland; nor has it been extracted from the cell, as have mucin and enzymes; but the facts force the conclusion that, like the gland cell, the muscle fiber has used its period of rest to make and store within itself an unstable compound which undergoes upon the application of a stimulus a very sudden chemical change. This unstable compound we may call the *fuel substance* or the *fuel* of the fiber.

9. Available and reserve fuel. The analogy of a match is useful to make clear these fundamental conceptions of muscular activity. The phosphorus on the head of the match is the unstable fuel substance; the friction of the match when it is rubbed against a rough surface is the stimulus, which is followed by a sudden chemical change in the fuel when the match "goes off." At this point, however, the analogy ends; for when a second stimulus is applied to a muscle within one tenth of a second, there is a second contraction, and in this second contraction there is the same sudden chemical change in the fuel; moreover, this stimulation may be repeated over and over again with like results. Even more striking is the fact that the same thing is true of a muscle removed from the body and consequently shut off from access to new fuel supply in the blood flowing through it. Such an excised muscle will give a long series of contractions upon the repeated application of stimuli. With the match or the percussion cap, on the other hand, such repeated discharges would not occur, for the entire stock of fuel is used up with each discharge.

In order to explain these facts, it is commonly assumed that the fuel substance of the muscle fiber exists in two forms: the one unstable and ready to be discharged by the stimulus; the other and larger part incapable of being discharged by the stimulus, but rapidly providing, after each discharge, the material to make good the loss of unstable fuel. We may speak of the one as the *available* or *unstable fuel* and of the other as the *reserve fuel.*

10. The chemical change of unstable fuel into waste products involves cleavage and oxidation. Although our present knowledge is inadequate to the full understanding of the chemical changes in the muscle during activity, it can at least be stated that changes of two kinds are involved, namely oxidation and cleavage.

Oxidation is the union of the material with oxygen, one of the gases of the atmosphere. When carbon (charcoal) is burned, for example, it disappears by uniting with oxygen to form the colorless gas, carbon dioxide; when hydrogen is burned, it unites with oxygen to form water; or if a chemical compound of carbon and hydrogen (for example, kerosene) is burned, its carbon unites with oxygen to form carbon dioxide, while its hydrogen unites with oxygen to form water. Conversely, when we find that the products of any chemical change contain more oxygen than the original substance, we infer that the change is a combustion or, as it is generally called, an oxidation.

The second kind of chemical change, *cleavage*, takes place without the addition of oxygen or, indeed, of any other chemical element, except that water is often added to the material changed. In this process the combination of different atoms which makes the compound is broken and the molecule is split into two or more molecules.[1] Thus new compounds or substances are formed.

In the muscle fiber both these changes occur during contraction. Many, perhaps the majority of physiologists, now think that the stimulus to the muscle fiber (nerve impulse, electric shock) first causes a cleavage of the unstable fuel of the fiber into lactic acid and possibly other products and that this cleavage is the cause of the contraction; under normal conditions this is *followed* by an oxidation of the lactic acid to carbon dioxide and water

$$C_3H_6O_3 + 3\,O_2 = 3\,CO_2 + 3\,H_2O.$$

On this view the cleavage takes place very suddenly (perhaps requiring less than the hundredth of a second), while the oxidation which follows requires several seconds or even minutes for completion; indeed, before it is complete, some of the lactic acid may have passed out of the muscle fiber into the lymph and blood. Some of the facts supporting this view are the following: the lactic acid produced within the muscle during contraction increases with the intensity of the work; the amount of it found after contraction is greater when the supply of oxygen from the blood is diminished or cut off; and, finally, lactic acid disappears from the muscle more rapidly after contraction, when the blood is well supplied with oxygen, than when it is deficient in that element.

[1] Matter is composed of *atoms* of chemical elements; these atoms are combined or bound together to form *molecules*. A lump of sugar, for example, would be composed of an inconceivable number of molecules of sugar, and each molecule would consist of six atoms of carbon, twelve atoms of hydrogen, and six atoms of oxygen bound together in chemical combination. Sugar may undergo cleavage into lactic acid by splitting its molecule of twenty-four atoms into two molecules of twelve atoms. The chemist expresses this by the following equation:

$$C_6H_{12}O_6 = 2\,C_3H_6O_3.$$

Let us not lose sight of the central fact. The activity of a muscle fiber, like the activity of a gland cell, is the result of a chemical change within the cell. In both cases the food material derived from the blood is transformed into something else and activity is accompanied by the production of new substances. In the case of the gland these new substances, or part of them, go to form essential constituents of the secretion, and we see at once the end secured by the chemical change. In the case of the muscle the end is, at first sight, not so clear. The substances formed are not of obvious use to the body, and we have now to inquire how this chemical change serves the purpose of producing a muscular contraction.

11. Relation of the chemical changes to the work of muscular contraction. It is a familiar fact that chemical changes often yield power for work. The explosion of dynamite (a cleavage change), for example, will shatter large masses of rock; the oxidation of coal in a locomotive engine supplies the power to move a heavy train of cars. In both cases waste products are produced, and in the change which produces them power is liberated; but in order that this power may be utilized to do work, some mechanism is needed to apply it to the desired end. The burning of coal in an open grate liberates power, but in the absence of any mechanism adapted to that purpose, it does no work; the same coal burned under the boiler of an engine, with its mechanism of boiler, piston, driving rod, and wheels, moves the train of cars.

So it is with the muscle. Within the cytoplasm of the fiber are the myofibrils (p. 35), and there are convincing reasons for believing that the combination of myofibril and sarcoplasm constitutes the mechanism of the muscle fiber. The power liberated by the cleavage change acts upon this mechanism, causing the shortening and thickening of the myofibrils, whereby a pull is exerted on the tendon. Whether the subsequent oxidative changes also contribute power for the work or merely produce heat is still an open question.

12. Heat production by the working muscle. One other point of similarity between the working muscle fiber and the working steam engine should be pointed out; namely, that both produce heat. It is a familiar fact that muscular activity makes us feel warm. This is the direct result of the liberation of heat by the oxidations within the working muscle fiber. The same thing is true of the steam engine, the liberated heat going in that case to warm the engine or passing away in the gases which escape from the smokestack, steam vents, etc. It is important that the student of physiology bear clearly in mind this feature of muscular action, since the active muscles not only supply power for work but also the heat necessary to maintain the temperature of the body, and no muscle can be thrown into contraction without liberating a certain amount of heat. For a full discussion of this matter see Chapter XII.

13. The repair and maintenance of the cellular mechanism. Thus far we have considered only those chemical activities of gland and muscle cells which are directly concerned with secretion and contraction or which prepare the cell for the performance of these functions. This is only a part, however, of the work of living cells, for, like all machines, cells may be injured by overwork or by accident, and their parts (nucleus, cytoplasm, fibrils, etc.) must be kept in working order. Just here the living mechanism differs from the lifeless engine, for the living mechanism is itself capable of repairing damage to itself. The locomotive must be sent to the shops and be repaired by work done upon it by other machines; if the boiler rusts, it must be taken out and a new one put in; if the wheels wear unevenly, they must be made true again by turning in a lathe or new ones must be substituted; when the grate burns out, a new one must be put in its place. The living cell, on the other hand, itself makes these repairs from certain constituents of the same food out of which fuel and zymogen granules are made, and it does this by other chemical activities than those we have described and about which we possess only fragmentary knowledge at present. In picturing to ourselves the activities of these living mechanisms we must include all these chemical processes, those of maintenance and repair as well as those concerned immediately with the performance by each cell of its own special functions, such as secretion by a gland and contraction by a muscle.

14. Recapitulation. We have traced the character of the work done in the case of the gland and the muscle and have found that it is fundamentally the work of the cells of which the organs are composed. The cells of other organs are similarly constructed to do other kinds of work, and the character of their chemical changes and of the mechanisms for utilizing power varies accordingly; all, however, showing the same fundamental plan of working engines. The body is a community of groups of cells of different kinds, each kind doing some work more or less peculiar to itself. In addition to the two groups (gland and muscle cells) which we have studied, there are nerve cells in the brain, spinal cord, and elsewhere; cells which make blood corpuscles; cells which keep in repair the connective tissues (bone, gristle, tendon, and ligament); and many more, such as cells which manufacture or themselves form the lining of free surfaces, like the skin, the alimentary tract, the air passages, etc. The sum total or net result of the activities of these and other cells makes up the work of the body as a whole. The work of the body — the human organism, the human mechanism — is thus the outcome or resultant of the work of its different component cells.

CHAPTER V

WORK AND FATIGUE

While it is true, as shown in the last chapter, that capacity for work is one of the principal characteristics of the human body, no experience of daily life is more familiar than that work is followed by fatigue. This is true both of individual organs and of the organism as a whole; for fatigue may be either local, as when some one muscle is tired from hard work, or general, as when weariness affects all organs — those which have been resting as well as those which have been working.

We use the word "fatigue" in two different senses, and it is important that a distinction be clearly made between them. In the one sense the word means *the diminution of working capacity due to work.* In testing one's strength of grip or of back a second test, if made immediately, shows less work done than at the first test, and this is true whether or not we are conscious of fatigue or of diminished working power. If, however, a certain time be allowed for rest, the second test will give as good results as the first.

In the other sense the word refers to the *feeling of fatigue* which frequently, though not always, accompanies the diminution of working power. We may "feel tired" when we have been doing nothing, and conversely, under the influence of excitement or other causes we may experience no feeling of fatigue even when we are near the limit of our working power. Often in an exciting game the players do not know at the time that they are tired or even that their working power is lessened; and stories are told of soldiers in hasty retreat who feel that they must "drop in their tracks" until the discharge of musketry close behind stimulates them to move faster than ever.

The feeling of fatigue has its seat in the nervous system, and its study must be postponed until we have learned something of the physiology of the brain and spinal cord. In the present chapter we are not immediately concerned with this side of the question, but rather with the diminution of working power produced by work. Such fatigue must be measured not by our sensations but by the work accomplished, whether that work be physical or mental. And as we studied the physiology of work in its simplest form in a single working organ, such as a muscle or a gland, so we can best begin our study of diminished working power or fatigue in one of these same organs, namely, the skeletal muscle.

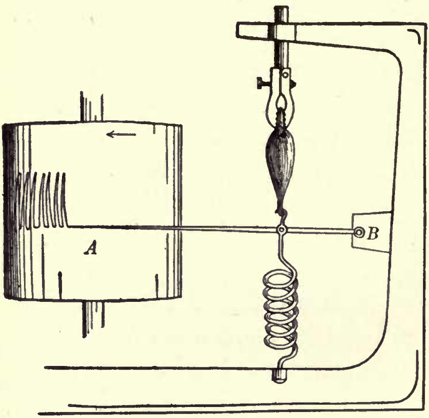


FIG. 33. Diagram of apparatus for recording successive muscular contractions

1. Fatigue of an isolated muscle and of a muscle with intact circulation. The course of fatigue in a muscle is best studied by causing the muscle to contract to its utmost, at regular intervals of time, against the resistance of a suitable spring. If now we record the height of each contraction, we obtain a series which shows at once the effect of the work on the working power; that is, the course of fatigue. Fig. 33 gives a diagram of the arrangement of such an experiment with an isolated muscle; that is, a living muscle detached from the rest of the body. One tendon is made fast in a rigid clamp, while the other is attached to the spring, which is stretched by the contraction when the muscle is stimulated. The length of the line written by the lever *AB* records what the muscle is capable of doing at the time; and if the records of successive contractions are made on the smoked surface of a slowly revolving drum, as in the figure, we have at once a record of the course of fatigue.

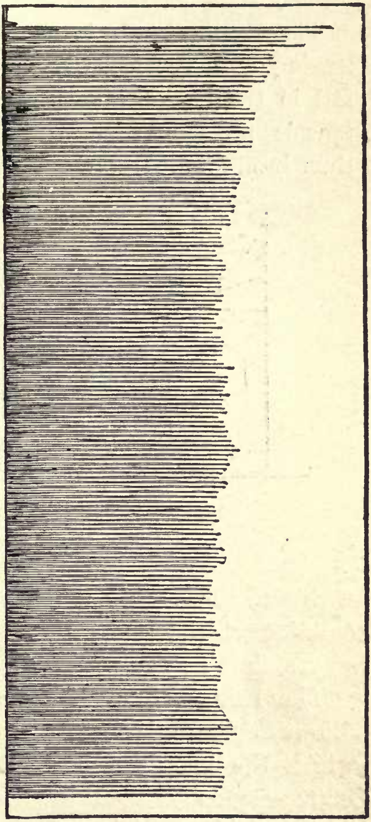


FIG. 34. Record of the successive contractions of the flexor muscles of the elbow joint

Showing the gradual decrease in working power to a fatigue level. The muscle contracted once every three seconds against the resistance of a strong spring, which was stretched each time as far as the strength of the muscle permitted

Such fatigue tracings may also be taken from a muscle within the body, and hence with its circulation intact. Thus the work of the biceps muscle in bending the arm at the elbow (Fig. 23) may be recorded by instruments essentially similar to that used with the excised muscle. In Fig. 34 we have reproduced a tracing of this kind.

It is quite evident that a continuous line joining the highest points reached by the several contractions will represent graphically the course of fatigue, and in Fig. 35 the line *a* represents this so-called "curve of fatigue" in the experiment whose results are given in Fig. 34. It falls off at first rather rapidly, then more and more slowly, until at last it becomes parallel with the base line. In other words, the muscle in this case finally finds a constant level of working power. This may be called the *fatigue level.*

The broken line *b* in Fig. 35 gives the result of a fatigue tracing with the isolated muscle. It will be seen that the fall in the height of contraction continues until at last the muscle no longer responds to stimulation. The contrast thus brought out between the effect of work upon muscles

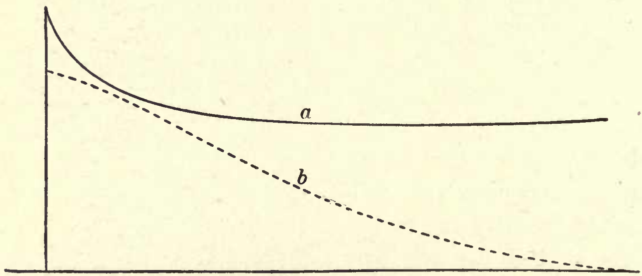


FIG. 35. Curves of fatigue

a, from a muscle with intact circulation; *b*, from an isolated muscle

with and those without the circulation suggests that the circulation of the blood through the working organ in some way maintains the working power.

The height of the fatigue level in the same muscle at different times is very closely dependent on the rate at which the muscle works. Thus with a contraction every four seconds instead of every three seconds the fatigue level would be higher than in Fig. 34; with a contraction every second it would be much lower. When the contractions come every nine or ten seconds there is usually no falling off in the work done, the time between contractions being sufficient for the complete recovery of working power.

This picture of fatigue hardly agrees with our feeling of fatigue, for the decline of working power begins at once, or at most after a very small number of contractions, whereas we usually notice fatigue only after work has gone on for a considerably longer time. One does not feel tired from walking, for example, during the first ten or twenty minutes of the walk. We need not discuss here just what makes us unconscious of the beginnings of fatigue; but it is important to understand that whether we are or are not aware of its presence, fatigue is the invariable and immediate result of all muscular work.

Weariness is simply the conscious feeling of fatigue, but fatigue is a physical condition of living cells and organs. Moreover, its phenomena are by no means confined to muscular work. When a gland is stimulated to vigorous secretion a diminution is sooner or later noted in the amount of the secretion, and there is some reason to believe that nerve cells may also become tired from continued activity. Fatigue, then, in one word, is a natural condition of an organ accompanying work, and we may proceed to inquire into its exact cause.

2. Waste products as a cause of fatigue. When blood which has been circulating through a fatigued muscle is sent through a resting muscle, the resting muscle shows signs of fatigue, even though it has itself done no work. Apparently the blood has extracted from the working muscle something which has the power of lessening the working capacity of a fresh muscle.

The same thing is illustrated by another experiment. A muscle which is deprived of its circulation (for example, by clamping its arteries and veins) is fatigued by vigorous work; it is then found that although when left to itself a slight recovery takes place, this recovery is much more marked if we first pass through its blood vessels a weak solution of salt. Here no food is supplied; the salt solution has only removed something from the fatigued muscle, which, in consequence of this treatment, recovers some of its working power.

Again, the mere exposure of a resting muscle to blood containing lactic acid or to blood heavily charged with carbon dioxide (CO_2) produces the condition of fatigue. Now in the last chapter it has been shown that both lactic acid and carbon dioxide are waste products of muscular activity; and these and other facts have led to the view, now generally received, that the waste products of the active organ interfere with the work of the organ and so constitute one of the main causes of fatigue. It is apparently for this reason that the injection of an extract of worked muscle fatigues fresh muscle, for the extract contains waste products. It is for the same reason that washing out a fatigued muscle with salt solution produces partial recovery, for the waste products of activity are in this way partially removed. We can also understand why fatigue always accompanies vigorous work. Waste products then necessarily accumulate and clog the living mechanism because they cannot be removed by the blood as fast as they are formed by the muscle cells. No fatigue occurs with only a single contraction every ten seconds or more because between contractions sufficient time is given to insure the complete removal of wastes.

3. Loss of fuel in the working muscle as a cause of fatigue. The blood, however, not only removes the wastes but also brings new food and oxygen with which the muscle makes good the loss of fuel; and it may well be — although it is not absolutely proved — that recovery from fatigue depends upon both of these good offices of the blood. We have certainly one well-established cause of fatigue, namely, the presence of the waste products of activity; and we recognize the probability that the depletion of fuel may also contribute to the result. But whether the first of these causes alone is sufficient to explain it, or whether both work together, we can understand that the maintenance of a good blood supply is of the first necessity and that undue fatigue can be avoided only by working at a moderate rate. It is an old and physiologically true saying that "it is the *pace* that kills."

4. Explanation of the fatigue level. In the experiment with the isolated muscle no waste products were removed nor were new food and oxygen supplied; hence the wastes in the muscle increased with each contraction, until at last their accumulation prevented all contraction. In the normal muscle the wastes likewise accumulate for a time; and this is why the curve of work at first falls (Fig. 34). It does not continue to fall, because as the wastes within the muscle increase in amount, the blood carries more and more of them away in a given time. The quantity of waste removed thus continues to increase until the same quantity is carried away from the muscle between two contractions as the muscle produces with each contraction. When this happens no further accumulation of waste is possible and the fatigue level is established.

5. General fatigue resulting from muscular activity. Everyone knows that after a day's tramp it is not simply the worked muscles which are unfit for good work, but that the brain, too, is tired, for hard mental work is then difficult or well-nigh impossible; and it is generally the fact that long-continued muscular work fatigues the brain more than brain (mental) work itself. The obvious explanation of this fact is that the waste products of muscular activity have accumulated in the blood more rapidly than the body can get rid of them, and so have fatigued the other tissues, including the nerve cells of the brain, just as the injection of the extract of a tired muscle lessens the working power of a fresh muscle. No doubt these same waste products may similarly fatigue gland cells; for experience seems to show that the secretion of digestive juices is not so active when one is suffering from muscular fatigue and that it is not wise to eat heavy meals when one is tired out. We can also understand why long-continued, vigorous muscular action produces marked fatigue in nerve cells and gland cells, while the activity of the latter produces only inappreciable fatigue in the muscles; for the amount of chemical change and the production of wastes are far greater in the case of muscular work than in that of nervous or glandular activity.

6. The analogy of the engine. In previous chapters we have compared the living body with a machine or locomotive engine; both do work, and both obtain the power for work from the chemical changes in food or fuel. What we have now learned about fatigue suggests an extension of the same comparison. Every locomotive suffers impairment of its working power with use, and special measures are taken to limit this impairment as much as possible; the gases and smoke are carried away at once by the chimney or smokestack; the furnace is provided with a grate so that the ashes shall not accumulate and shut off the draft; the bearings are oiled and foreign matters removed; finally, as the consumption of fuel goes on, the loss is made good by stoking.

The continuance of the work of the engine requires two things — fresh supplies of fuel and the removal of wastes. Obviously the blood performs these same offices for the cell. It supplies to the cell fuel (food) from the alimentary canal and oxygen from the lungs and it carries away the waste. Provision is thus made to maintain the human machine in working order and good condition during its activity. If the blood flows too slowly through the muscle, the same thing happens as in the locomotive when the fireman neglects to rake the fire or to put on new fuel; the efficiency both of the human engine and of the locomotive may be impaired either by the undue accumulation of the waste products of its own activity or by the neglect to supply proper food or fuel.

CHAPTER VI

THE INTERDEPENDENCE OF ORGANS AND OF CELLS

Internal Secretions

1. The products of cellular activity not necessarily harmful. We have now learned that the active living cells of the body are the seat of chemical changes which produce new substances; that the accumulation of these products of activity often limits the working power of the cells in which they are produced, and may even depress the activity of other cells to which they are carried by the blood. In the case of the skeletal muscles we have spoken of the carbon dioxide, the sarcolactic acid, etc. as "waste products," meaning thereby that they are incapable of serving as sources of power for the work of the muscle; and this term, together with the fact that they constitute one cause of fatigue, is apt to mislead us into supposing that they can be of no further use to the body or, even more, that they are necessarily harmful and that their presence in the blood is objectionable.

These conclusions, however, do not necessarily follow from the facts. It does not even follow that a substance which produces fatigue for that reason serves no useful purpose. Most adults can recall times when because of long-continued application to mental work or because of worry or other nervous strain they have become overexcitable and restless and have been unable to obtain the sleep of which the body as a whole stands in need. At such times sleep is often best secured by producing general fatigue through muscular work. The waste products, by their very act of fatiguing the overexcited nerve cells, may be of service to the body as a whole; and it is probably true that not only in such abnormal conditions but also in the daily conduct of life the fatigue of moderate muscular activity contributes its share toward inducing healthful and refreshing slumber.

Thus far we have considered the chemical activities of each organ as contributing to the work of the organ in which they occur and, because of the accumulation of waste products, as the occasional cause of undue interference with efficient activity, both in the working organ and elsewhere. And yet the familiar case which we have just cited suggests another view of the matter. The products of the chemical activity of one organ may be of service to other organs, and so to the body as a whole; and while their too rapid accumulation in the blood may be undesirable, their presence in moderate amounts may be beneficial and may contribute to the normal environment of the cells of the body.

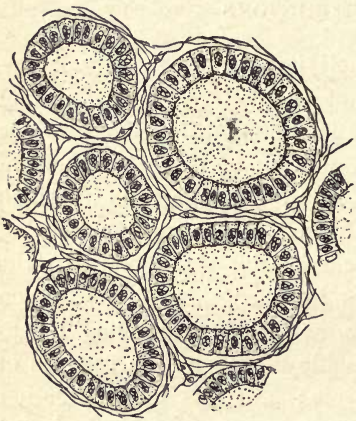


FIG. 36. Cross section of the thyroid gland

The cells secrete into the closed sacs, which they surround, the internal secretion, which then passes out between the cells into the lymph spaces of the connective tissue

2. The thyroid gland. This view of the case is strikingly emphasized in the physiology of the thyroid gland — a small organ in the neck, the two chief lobes of which lie alongside the trachea. For a long time its use was not understood, and at times it was even supposed that it plays no important part in the life of the body as a whole. It has been found by experiment, however, that removal of the thyroid is followed by a disease in all respects similar to one which had long been observed in human beings, especially in children;

and this fact suggested that the disease is due to the failure of the thyroid to perform its normal functions.

The subject was further cleared up by the discovery that after the removal of the thyroid in a lower animal the disease in question could be prevented by feeding the animal thyroids or even by giving to it a certain substance extracted from them. Evidently the thyroid manufactures and discharges into the blood a peculiar substance necessary to the healthy life of the cells of the body; and when the gland fails to manufacture this substance it can still be supplied artificially by introducing it into the blood by absorption from the alimentary canal.

3. Internal secretions. In our study of secretion in Chapter IV (p. 43) we dealt only with glands which discharge their principal products through a duct into some part of the alimentary canal; such glands are the salivary glands, the pancreas, and the liver. Other glands send ducts to the surface of the body — for example, the sweat glands, which discharge perspiration upon the skin; and the lachrymal glands, which discharge the tears on the eyeball. In the case of the thyroid, on the other hand, we have an example of an organ which, like those just mentioned, manufactures a special substance from the blood, but, having no duct, contributes the products of its manufacture to the blood, for the use of other cells. This process is spoken of as *internal secretion*, to distinguish it from ordinary secretion, in which case something is discharged on a free surface like the skin or into the alimentary canal, the nasal cavity, or the air passages.

4. The adrenal glands. Lying immediately above the kidneys are two small glandular organs, the adrenals, which, like the thyroid, were formerly considered of minor importance. It has been shown, however, that these also contribute to the blood a most important internal secretion known as *adrenaline.* This substance is manufactured by the gland cells and, during their periods of inactivity, is stored within the cells, from which it is discharged by nervous impulses. Like the thyroids, the adrenals have no ducts; but the cells of the gland come into very close relation with the unusually rich network of blood capillaries into which the adrenaline is discharged when the gland is stimulated by its nerves.

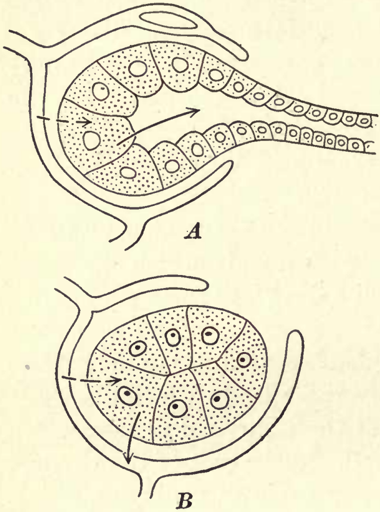


FIG. 37. Diagrams of external (*A*) and internal (*B*) secretion

The passage of food material from the capillaries into the gland cells is represented by the arrows with broken lines; the path of discharge of the secretion, in *A* into the duct and in *B* into the blood, is indicated by the arrows with unbroken lines

Once in the blood, adrenaline produces profound effects in many organs of the body. Among these may be mentioned a decrease in the blood supply to the digestive organs; a change in the beat of the heart; an increased flow of blood through the brain, the skeletal muscles, and, to a less extent, the skin; the discharge of sugar into the blood by the liver; and an increase in the number of the red blood corpuscles (see p. 136).

It is a most significant fact that many if not most of the reactions of the organism to adrenaline are the very reactions which are needed in times of great muscular exertion. For example, the shifting of the blood from digestive organs to the working muscles and to the brain, which is thereby rendered more alert; the supply of increased quantities of sugar to serve as power for muscular work; the assistance to the heart, which is called upon at such times to pump more blood; the augmented oxygen-carrying capacity of the blood by increase of its red corpuscles — all these reactions place at the disposal of the muscles and nervous system the conditions for maintaining intense work for comparatively brief periods of time, and all this is done by the simple expedient of discharging from one of the organs of the body an internal secretion on the blood.

Finally, that adrenaline does in fact serve the purpose of placing the body in condition to perform intense muscular work is rendered probable by the discovery that conditions of emotional excitement, especially those of fear or anger, cause the discharge of nervous impulses to the adrenals. Among animals it is these very emotions which accompany or at least precede the most vigorous muscular activity, fear going along with flight and anger with combat. This suggests that these emotions serve the purpose of calling forth the utmost of which the animal is capable in preserving its very existence.

5. Other examples of internal secretion. An equally remarkable discovery has shown that the pancreas not only manufactures an important digestive juice (pancreatic juice) which it discharges into the intestine through its duct (pancreatic duct, see Fig. 54) but also produces another substance which is necessary, in order that other organs may use the sugar which is in their food. Here we have an example of an organ which produces both an ordinary and an internal secretion, and the same thing seems to be true of the kidney, as it certainly is of the liver.

Much attention has recently been given to the study of another ductless gland, the *pituitary body*, situated in the bone between the roof of the nasal cavity and the base of the brain (see Fig. 14). There is good reason for thinking that this gland contributes an important internal secretion to the blood and that certain organs of the body fail to act normally when this secretion is deficient; serious results also follow an excessive secretion. Incidentally it may be mentioned that it is widely held that excessive secretion of the thyroid leads to a very serious condition, known as Graves's disease or exophthalmic goiter, just as deficiency of the secretion leads to the entirely different disease to which we have already referred.

Thus, through the medium of the blood the chemical activity of one organ may affect the life of other organs favorably or unfavorably. All the cells of the body help to make the blood what it is, many of them contributing to it something useful or even necessary to other cells. The work of the body is not merely the sum total of the work of its separate cells, each working for itself alone and performing a single function; between the cells an exchange of products often takes place, so that cells become both serviceable to and dependent upon one another for the material needed to carry out their own special chemical activities. And what is true of cells is no less true of organs; these also are interdependent, ministering to one another.

CHAPTER VII

THE ADJUSTMENT OR COÖRDINATION OF THE WORK OF ORGANS AND CELLS

A great physiologist once said, "Science is not a body of facts; it is the explanation of facts." Some of the most important chapters of science are those which seek to explain facts so well known and obvious that we are apt to forget that they need explanation. When anything irritates the lining of the nasal cavity we sneeze; when it irritates the larynx we cough; when it irritates the exposed surface of the eyeball we wink. These three facts are well enough known; but it is safe to say that anyone considering the matter for the first time would find it difficult to explain how it comes about that anything going "down the wrong way" does not make us sneeze or wink, but sets us to coughing. The answer to the general question thus raised is the subject of this chapter, which considers the adjustment of the work of the individual cells and organs of the body, each to do its work at the proper time and so to play its due part in the work of the organism as a whole.

The more we think of it, the more wonderful does this fact of adjustment appear. The millions of living cells are in a way individual units, and communities of individuals do not invariably work together. Let us compare the human body in this respect with bodies or groups of men or boys. In a game of football each team is a body of eleven individuals, and each individual is assigned to a definite position to do definite things as occasion arises. Theoretically, under given conditions of the game it is the work, or *function*, of the "left tackle" to prevent a certain player of the opposing side from making a certain play. But there is always a doubt whether he will do this thing or "lose his head" and do something else, leaving his man free to do what he pleases. In the latter case that organism which we call a football eleven would act very much as the human organism would act if it were to wink and not cough when a foreign body lodges on the lining membrane of the larynx.

Evidently we have something here to explain. Why are the actions of the body *purposeful*; that is, adapted to accomplish the right thing at the proper time? And in the more complicated actions how is the work of the different units — the organs and the cells — adjusted, or *coördinated*; that is to say, how is each one made to do its proper share of the work? Let us begin with the study of a very simple action — that of winking.

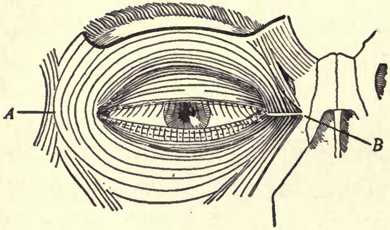


FIG. 38. The muscular mechanism of winking

1. Winking is caused by the contraction of muscle fibers which run transversely across the eyelid in a curved course. As they are attached most firmly at the regions *A* and *B* (Fig. 38), their shortening straightens their arched course and so brings the two edges of the eyelid into contact. The work of this muscle is obviously purposeful, for the wink takes place when the eyeball needs protection; it is also coördinated, since the act is executed by a number of fibers working together, for if only those of the lower eyelid were to contract the lids could not be closed.

The muscle fibers which work together to produce the wink do not originate their own activity. They merely do what they are *stimulated* to do by the nervous impulse, which acts upon the muscular fuel substance somewhat as a fuse acts upon a charge of gunpowder. Even the amount of contraction is determined by the strength of the nervous impulse, a strong impulse producing greater contraction than a weak impulse. In health the muscle fibers are the obedient servants of the nerves, and if they act in a purposeful and coördinated manner, it is because the nerves stimulate them to act in this way. The explanation of purposeful and coördinated action must therefore be sought

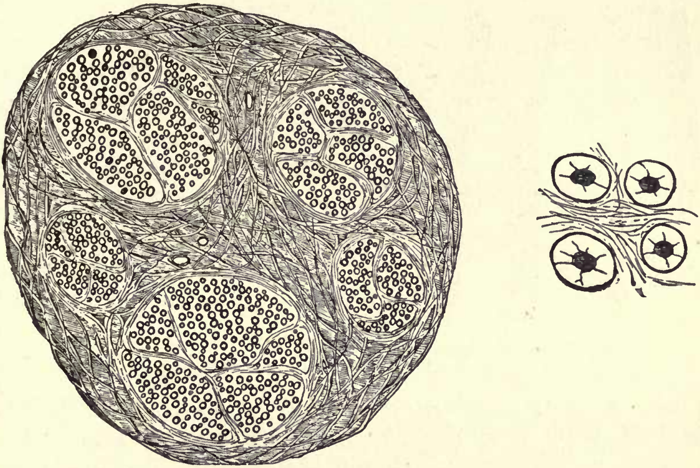


FIG. 39. Cross section of a nerve

Showing five bundles of nerve fibers bound together by connective tissue containing a few blood vessels. On the right are shown four fibers more highly magnified, the dark center being the axon, around which is the white or fatty sheath, both axon and fatty sheath being inclosed within the fine membrane, the neurilemma. Cf. Fig. 40

not in the muscles but, behind these, in the nervous system, to the study of which we now turn.

2. Structure of a nerve. A nerve, like a muscle, may be separated into long fibers (Fig. 40) which are bound together by connective tissue containing blood vessels, lymph spaces, and lymphatics. The *nerve fiber*, which is the essential part of the nerve, just as the muscle fiber is of the muscle, differs somewhat in structure in different nerves; it generally consists of a central threadlike core surrounded by a fatty sheath, the latter being, therefore, shaped like a hollow cylinder, — which, however, is interrupted at intervals of about one millimeter, — and both of these are enveloped in a delicate membrane comparable to the sarcolemma of the muscle fiber. Such fibers are from about $\frac{1}{5000}$ to $\frac{1}{1000}$ of an inch in diameter (compare the diameter of a muscle fiber, p. 34).

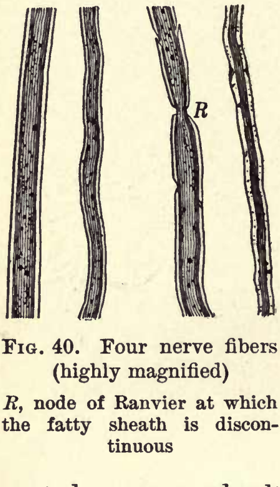


Fig. 40. Four nerve fibers (highly magnified)

R, node of Ranvier at which the fatty sheath is discontinuous

There are, however, nerve fibers which have no fatty sheath, and others which are destitute of membrane. The essential part of the fiber is the threadlike portion in the center; this is never absent from nerves and is known as the *axon*, or *axis cylinder*.

3. The axon of a nerve fiber is a branch of a nerve cell. By suitable methods these axons may be traced along the nerve of which they form part and even into the brain and spinal cord; it is then found that they pursue an uninterrupted course and ultimately become continuous with the cytoplasm of a *nerve cell*. Nerve cells are found in the brain, in the spinal cord, in enlargements (*ganglia*) on certain nerves, and even alone in the connective tissue of many organs of the body, as the heart, the intestine, etc. By far the greater number are in the brain and spinal cord, and in some cases the axons to which they give rise are of very considerable length; those of the muscles of the foot, for example, reach from cells in the sacral region of the spinal cord to the extremity of the foot. Such fibers would be over a yard long and less than $\frac{1}{1000}$ of an inch wide, and we may regard the cell whose main portion is in the sacral cord as sending out a branch, or *process*, from this region to the foot.

Furthermore, recent investigations have led to the generally accepted conclusion that *each axon is a part of only one nerve cell*; a single cell may give off more than one axon, but the axon is never connected with more than one nerve cell. Of these cells and of their connections with nerve

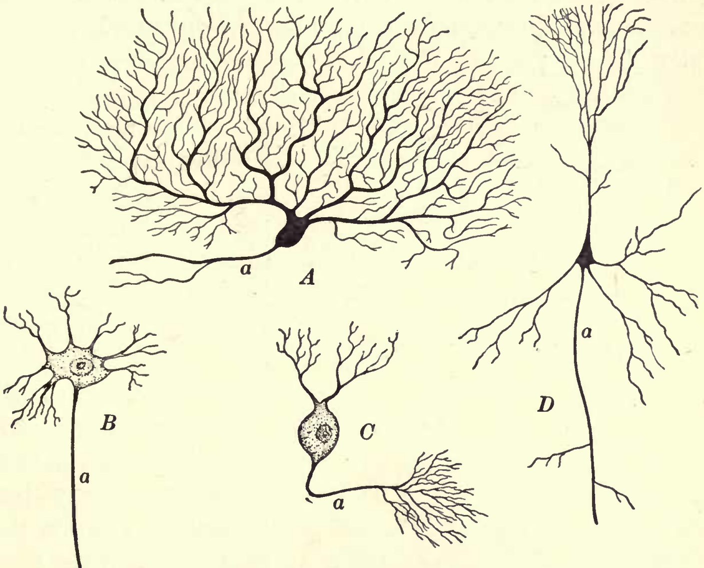


FIG. 41. Four nerve cells

A and *C*, from the cerebellum; *B*, from the gray matter of the spinal cord; *D*, from the cerebrum; *a*, the axon. The cells *A* and *D* are stained so that the main body and the dendrites (p. 75) are a uniform black; *B* and *C* are stained so as to show the nucleus and the cytoplasm

fibers we can get a more definite picture by an examination of the structure of the spinal cord.

4. Structure of the spinal cord. When the vertebral canal is opened a whitish cord is found within it, — *the spinal cord*, — from each side of which arise thirty-one pairs of nerves, or, in general, one pair for each vertebra. One nerve of each pair arises on the ventral side of the cord, the other on the dorsal side. These nerves are known as the ventral and dorsal *nerve roots*[1] respectively. On the dorsal nerve root, some distance from the cord, there is a slight enlargement, or ganglion. Just outside this ganglion the two roots unite, and from their union nerves pass to the skin, the muscles, the blood vessels, the viscera, etc.

The spinal cord itself in cross section shows a darker central core, known as the *gray matter*, surrounded by an outer lighter portion, the *white matter*. The white matter consists essentially of nerve fibers which run lengthwise of the cord and here and there send branches into the gray matter; it may be regarded as a large nerve. The gray matter, on the other hand, contains a mesh of fibers and, in addition, numerous nerve cells. There is the same difference everywhere between the white and gray matter of the nervous system; the arrangement in the brain is not so simple as in the cord, but here also the white matter consists of fibers running from one part of the nervous system to another, while the masses of gray matter always include collections of nerve cells.

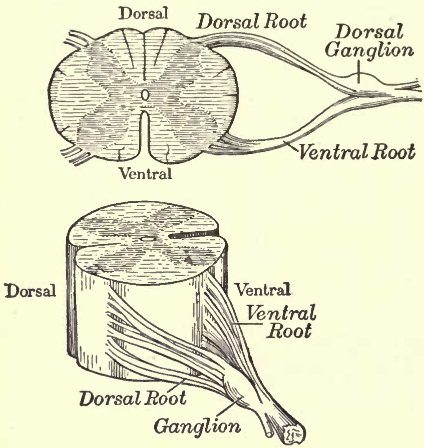


FIG. 42. The origin of the dorsal and ventral nerve roots of a segment of the spinal cord

5. Fibers of the ventral, or anterior, nerve root. These fibers may be traced into the spinal cord. It is then found that the nerve cells from which they arise lie in the gray matter in the immediate neighborhood of the root to which

[1] The older anatomical terms and those even to-day more generally used are "anterior" and "posterior," instead of "ventral" and "dorsal."

they belong; that is, the fibers of the roots do not come from higher or lower parts of the cord or from the brain. It has been found that when these roots are stimulated they throw muscles into contraction and produce effects on the blood vessels and glands, but they do not give rise to sensations or produce other effects in the cord itself. In other words, *the fibers of the ventral root conduct impulses from the cells of the spinal cord outward*; they do not conduct impulses from outside into the spinal cord. Hence they are known as *efferent* fibers (Latin *ex*, "out of"; *ferre*, "to carry").

The nerve cells from which these fibers arise consist of a mass of cytoplasm around the nucleus and of one or more outgrowths of this cytoplasm, usually more or less branched. These outgrowths of the cytoplasm divide and subdivide, ultimately forming in the gray matter exceedingly fine terminal branches like those of a tree in the air. Such processes are known as *dendrites* (Greek *dendron*, "a tree"). The nerve cells in question have numerous dendritic processes; in other nerve cells there may be but one, and still others possess no dendritic processes at all. In all cases the general appearance of the cell depends largely upon the number and manner of branching of these dendrites. Thus it happens that nerve cells differ from one another in appearance just as a Lombardy poplar, an oak, an elm, and a maple differ, although all show the fundamental characteristics of a tree (Fig. 41; see also Figs. 109, 110, and 111).

In subsequent portions of this work it is unnecessary for us to go into the details of the form of the nerve cells to any extent; the student need only understand henceforward that nerve cells consist of a central mass of nucleated cytoplasm from which proceed outgrowths, or processes, which are of two kinds: (1) those which become *axons* of nerve fibers and which form an essential part of all nerve cells; and (2) the *dendrites*, which are usually but not always present. The whole structure, including the central cell body with its dendrites and axons, is an anatomical unit — a cell. To this entire cell the term "neurone" is given. The neurone is the cellular unit of the nervous system, just as the muscle fiber is the cellular unit of the muscle, and the gland cell of the gland.

6. Fibers of the dorsal, or posterior, roots. The ventral roots, as we have seen, are entirely efferent in function; that is, they conduct impulses only away from the spinal

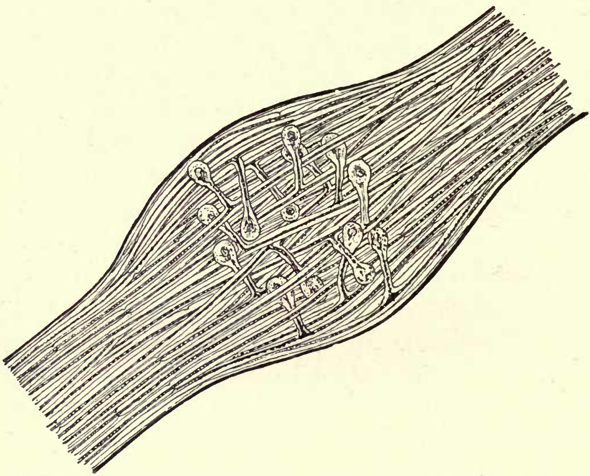


FIG. 43. Semidiagrammatic longitudinal section of a ganglion of the dorsal (posterior) root

cord. The dorsal, or posterior, roots, on the other hand, are found to be essentially *afferent* (Latin *ad*, "to"; *ferre*, "to carry"); that is, *they carry impulses from outside toward and into the spinal cord.* This is shown by the fact that when these roots are destroyed by disease, muscles can still be thrown into contraction, glands will still secrete, etc., — that is, there is no interference with efferent impulses, — but no sensations are received from the part of the body to which these nerves are distributed; pinching the skin is not felt; the flesh may be burned and its owner suffer no pain. Since these results never follow destruction of the ventral roots, we must conclude that *impulses enter the cord solely by the dorsal roots precisely as they leave the cord solely by the ventral roots.*

It has been stated above (p. 74) that there is a ganglion on the dorsal root. Microscopic study of this ganglion shows that the fibers of the dorsal root pass through it and that each fiber gives off at right angles to itself a branch which becomes continuous with a pear-shaped nerve cell of the ganglion. These cells have no other processes. We may express the relation between the pear-shaped cells of the ganglion and the fibers of the dorsal root by saying that the single axon from the main cell body divides into two in the ganglion, one branch passing outward to the periphery, the other passing centrally into the spinal cord (Fig. 43).

7. Endings of the peripheral branches of the neurones of the dorsal root in sense organs. The peripheral branch ultimately ends in some "sense organ," one of the most important of which, so far as the spinal nerves are concerned, is the skin. The eye, the ear, the nose, the mouth, are examples of other sense organs, and they all contain the peripheral endings of afferent neurones. Each is sensitive to some special influence from without, as the eye to light, the ear to sound, etc.; and when stimulated they start nerve impulses moving inward along the nerves toward the brain or cord.

8. Ending in the spinal cord of the central branch of the neurones of the dorsal root. The other or central branch passes into the spinal cord. It does not, however, like the neurones of the ventral root, there become continuous with the nerve cells of the gray matter,[1] but divides, on entering the cord, into an ascending and a descending branch (Fig. 44), each of which runs for a longer or shorter distance in the white matter of the cord. Indeed, many of the ascending

[1] It is, as has already been pointed out on this page, part of a nerve cell in the ganglion of the dorsal root.

branches extend as far anteriorly as the lower parts of the brain. As shown in the figure, these branches give off at right angles to themselves subbranches (the *collaterals*), each of which enters the gray matter and ends there by breaking up into a tuft of extremely fine fibrils, the *synapse.* The synapse is in close proximity to, and possibly in a kind of anatomical continuity with, the dendrites or the main body

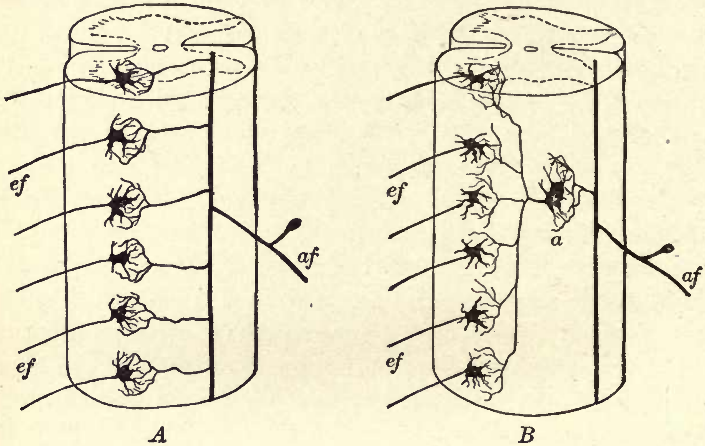


FIG. 44. Relation of afferent (*af*) to efferent (*ef*) neurones of the spinal cord In *A* the single afferent neurone branches into six collaterals, each of which ends in a synapse around an efferent cell. In *B* the connection is made through the agency of the cell *a*, as explained in section 13

of a nerve cell of the gray matter. Each afferent neurone, then, is a cell whose main body is in the ganglion of the dorsal root and whose branches, or arms, reach out, one of them to a peripheral sense organ and the other to the gray matter of the spinal cord and brain, where they end in synapses. *By means of the synapses the afferent neurone excites or stimulates other neurones.*

9. Anatomical relation of afferent to efferent neurones. We may now put together what we have learned about the neurones of the ventral and those of the dorsal root; we then obtain a plan like that shown in Fig. 44, and such, *in principle* at least, represents the manner in which the afferent neurone is brought into relation with efferent neurones.

Afferent and efferent fibers enter and leave portions of the brain in much the same way, although the separation into ventral and dorsal roots is not obvious. We may therefore take the above scheme as typical of the relation between these two kinds of neurones — those of the brain as well as those of the cord.

10. Application of these facts of structure in the explanation of purposeful and coördinated action. The diagram in Fig. 45 readily explains why the sudden appearance of an object in front of the eye causes us to wink and not cough; that is to say, it explains the purposeful character of this so-called reflex action. The formation of the image of the object on the retina, a sense organ, starts impulses along the fibers of the afferent optic nerve; these fibers extend into the brain, and their synapses end around *and stimulate* those efferent nerve cells which stimulate the muscles of the eyelid. The action is purposeful because the fibers of the optic nerve end around these cells and not around those which, for example, innervate[1] the muscles which open the mouth or flex the finger (Fig. 45).

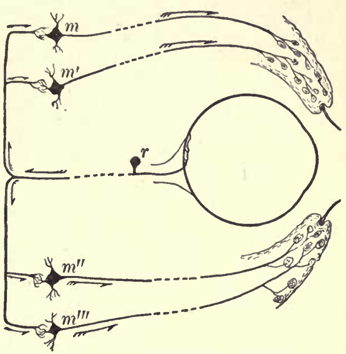


Fig. 45. Diagram of the nervous mechanism by which a wink is produced by the sudden appearance of an object in front of the eye

r, afferent neurone of the optic nerve; *m*, *m'*, *m''*, *m'''*, efferent neurones to the muscles of the eyelid

Our diagram also gives the basis of coördination — the combination of the work of different muscle fibers in orderly harmonious action. The system of collaterals on the central

[1] That is, supply with nerve fibers.

branch of the afferent neurone is obviously a mechanism to combine the action of the efferent neurones in this way. The diagram also gives a clew, at least, to the explanation of another element of coördination: when two or more muscles work together to accomplish a given act, one of the muscles usually works harder than another; not only must they work together, but the amount of force exerted by each must be adjusted to the needs of the movement as a whole. This adjustment is most probably effected by differences in the connection of the synapses with their cells; thus those muscles which contract most forcibly are innervated by neurones whose dendrites and main cell body come into more intimate contact with the synapses of the afferent neurone; or the number of fibrils of the synapse may be greater in their case than in the others. These, however, are only possibilities; the whole subject requires further elucidation.

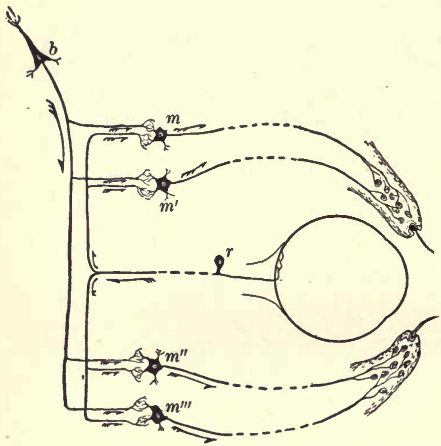


FIG. 46. Diagram of the nervous mechanism represented in Fig. 45, with the addition of the neuron *b* (see sect. 12)

11. Definition of reflex action. An action such as we have just been studying is known as a reflex[1] action. By this we mean *an action called forth by the more or less direct action of afferent upon efferent neurones and without the intervention of*

[1] The word literally suggests the idea of reflection from the afferent to the efferent neurones, as light is reflected from a surface; but the student has already learned enough to understand that efferent impulses are something more than mere mechanical reflections, or rebounds, of afferent impulses.

the will. The afferent neurone may be stimulated by some external agent, such as light, heat, sound, pressure, etc., or by some condition within the body itself, as when diseased or abnormal conditions of the stomach or some other organ induce vomiting.

It is a common error to suppose that all actions which are not called forth by the will are reflex. The essential feature of a true reflex is the more or less direct action of the afferent impulses on efferent neurones and not merely its nonvolitional character. There are, in fact, involuntary actions in which the efferent neurones are directly stimulated not by afferent neurones, but by the condition of the blood or in other ways. Such actions are not reflex, though they may be either involuntary or unconscious or both. They are known, in general, as *automatic actions*, and we shall meet examples of them as we proceed with the study of the various functions of the body.

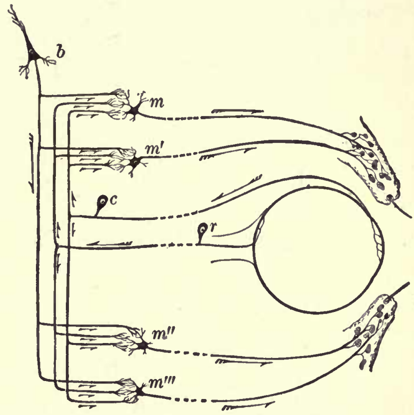


FIG. 47. The nervous mechanism shown in Fig. 46, with the addition of the afferent neurone *c*, from the cornea (see sect. 12)

12. Actions resulting from stimulation by the will. A wink is not always a reflex action. We can wink "on purpose," or, otherwise expressed, a wink may be called forth by the will and entirely apart from the sudden appearance of some object in front of the eye. Here the muscles of the eyelid act in exactly the same manner as in a reflex wink, which means that they are stimulated in the same way by the same efferent neurones. Thus far the mechanism is the same in the two cases, but the source of stimulation of the efferent neurones must be different.

In later chapters of this book we shall bring forward evidence to show that the exercise of the will (volition) requires the coöperation of the highest portion of the brain or cerebrum. Nerve cells in the gray matter of the cerebrum send off axons which pass downward to those portions of the brain and spinal cord from which the motor or efferent neurones arise; with the neurones of these nerves they make exactly the same kind of connections (collaterals and synapses) as are made by the afferent fibers from the retina which excite the reflex (see Fig. 46, in which *b* is the cerebral neurone).

The collaterals and synapses of the cerebral neurone (which, it will be observed, is entirely confined to the central nervous system) simply duplicate those of the afferent neurone; hence the two neurones produce the same result.

There is, however, still a third way in which winking may be stimulated. When the cornea of the eye begins to dry, a reflex wink spreads tears over the eyeball. In this case we have to deal with a second reflex, the afferent neurones being not those in the optic nerve, but those in what is known as the trigeminal, the sensory nerve of the cornea. Our scheme thus becomes that shown in Fig. 47.

13. The "master" neurone. The multiplication of collaterals and arborizations which this scheme involves would seem to be largely avoided by the presence of a third neurone between those which stimulate the action and the efferent neurones which directly act on the muscles (Fig. 48).

In this way, when a wink is produced, whether from the cerebrum or from the retina or from the cornea, the single cell *a* is stimulated, and this in turn stimulates the groups of efferent neurones which immediately innervate the muscles of the eyelids. Many of the nerve fibers of the cord and brain belong to neurones which perform the same function as that attributed to the cell *a* in our diagram. They are entirely confined to the brain or cord and group together those efferent cells which by working together produce a coördinated action.

The organization of the nervous system is, in fact, much like that of a large manufacturing establishment. The nerve cells which send axons to the muscles, glands, blood vessels, etc. may be compared with the operatives, each with his special task to perform; over these are foremen, or "bosses," from whom they take their orders or, in physiological language, who stimulate them to do their work and who would correspond to cells like *a* in Fig. 48. The foremen in turn receive orders, now from one department of the establishment, now from another, as the work of their operatives is needed in making one or the other of the products offered for sale. So the master neurones receive stimuli from the brain or from afferent nerves, as the needs or the desires of the organism as a whole require their activity. The comparison is instructive and may easily be carried out in greater detail by the student himself.

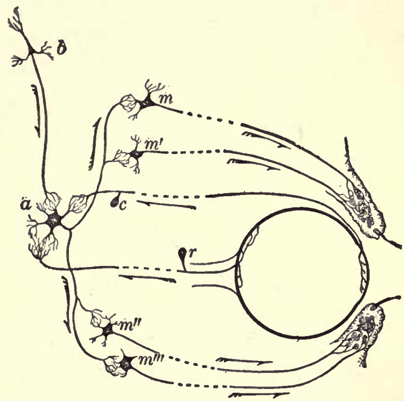


FIG. 48. The master neurone

14. The coördination of two or more actions to achieve a definite end. These conceptions will become more definite if we study the nervous mechanisms represented in Fig. 49, which represents the combination of the wink with different physiological actions, according to the nature of the conditions which call it forth. Let us consider the two reflex winks already referred to, that from the cornea and that from the retina. The wink from the cornea is for the purpose of spreading tears over the surface of the eyeball and, to be effective, must be accompanied by a secretion of tears. We may suppose that this is accomplished, as in the diagram, by the afferent neurone (c) from the cornea stimulating two master neurones, one of which (m^w) produces the wink, while the other (m^t) stimulates the tear glands to secrete.

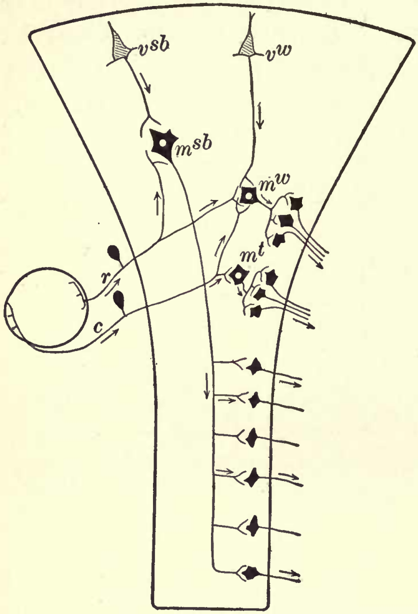


FIG. 49. Coördinations involved in the combination of the wink with other actions

The afferent neurones r, from the retina, and c, from the cornea, connect with different combinations of efferent neurones as explained in the text. Efferent master neurones are shown as follows: m^w, for winking; m^t, for secretion of tears; m^{sb}, for starting back. Neurones concerned in volitional actions are v^{sb}, for starting back, and v^w, for winking

The wink from the retina, on the other hand, has the entirely different purpose of preventing the contact of foreign objects with the cornea. For this purpose tears are not necessary and they are not secreted. But at times this wink is accompanied by a sudden starting back of the body as a whole to avoid the threatened danger. In this case we may suppose that the afferent neurone from the retina connects with the master neurones m^w, for winking, and m^{sb}, for starting back, but that this afferent neurone does not connect with m^t, for the secretion of tears.

Finally, the volitional neurones v^{sb} and v^w, which pass from the cerebrum to their appropriate master neurones, call forth these actions of starting back or winking *as separate acts.*

15. The acquisition of reflexes; conditioned and unconditioned reflexes. There can be no doubt that many of these reflex mechanisms are born with us. A newborn baby, for example, like the adult, winks and secretes tears when the cornea dries; it secretes saliva when a sapid substance is placed in the mouth; it swallows when something touches the throat; if a cane is brought in contact with the palm of the hand, it is grasped firmly. These and many other reflex actions take place from the first because the baby inherits and hence is born with the complete reflex mechanism for their execution upon the application of the appropriate stimuli.

On the other hand, new involuntary reactions can be acquired in adult life, even reactions which are useless to the body. The extent to which this is true is illustrated by the following extreme case: if a piece of ice is applied to a definite spot of the skin, the amount of blood flowing through that part of the skin is greatly diminished and the skin becomes pale. This is an inherited reflex which (Chap. XII) protects the body from exposure to cold. A morsel of food placed on the tongue (where it stimulates the afferent nerves of taste) will reflexly excite the flow of saliva. In both cases we see the obvious purposeful relation between the stimulus and the reaction and in both cases we are dealing with inherited reflexes. Moreover, these two reflex mechanisms as inherited are entirely independent of each other, for the stimulation of the skin by ice does not excite the flow of saliva nor does the stimulation of the sense of taste influence the blood flow through the skin. If, however, every time that one eats, a piece of ice is applied to the same region of skin, so that *both these reflexes are simultaneously excited*, in the course of two weeks or more it will be found that the application of ice to the skin *excites a flow of saliva even though no food is taken into the mouth.* In other words, these two reflex mechanisms have become *associated*, so that activity of the one now discharges the other. Evidently some sort of nervous connection has been established between them. Fig. 50 gives a diagram of the new association which has been established between the two centers.

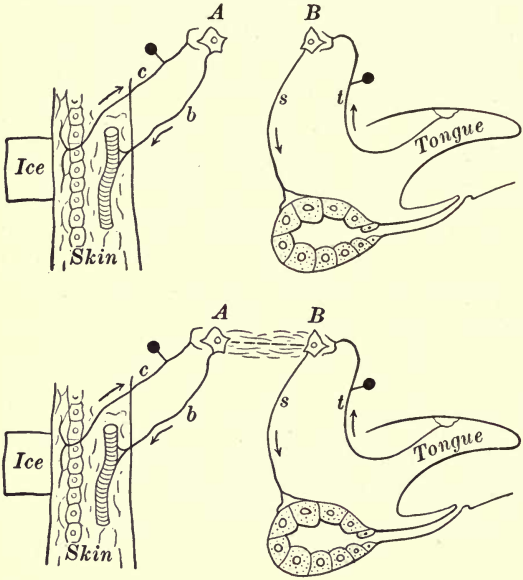


Fig. 50. The acquisition of a conditioned reflex

A, reflex mechanism for constriction of cutaneous vessels when cold is applied to the skin; *B*, reflex mechanism of the secretion of saliva when a sapid substance comes in contact with the tongue. Above is shown the usual normal condition with no connection between the two mechanisms; below, the condition after both have been repeatedly in simultaneous action

The connection thus newly established between the afferent neurones of cold (*c*) and the efferent neurones to the salivary glands (*s*) differs in several ways from the connection between the afferent and efferent sides of an inherited nervous mechanism. Such acquired reactions are not evoked with the same certainty as the inherited and, once acquired, they are more readily lost by disuse. Whether we get the reaction or not depends upon the condition of the body at the time we apply the stimulus. Hence they are spoken of as *conditioned reflexes*, to distinguish them from the *unconditioned* (or inherited) *reflexes*. Undoubtedly many of our involuntary actions, especially acquired habits in general, are conditioned reflexes acquired since birth and thus added on to the stock of inherited reflexes which make part of the equipment with which we begin life.

16. The complexity of the mechanisms of the nervous system. Such actions as we have been studying — whether the inherited reflex of winking, even when this is combined with other acts like the secretion of tears, or the acquired conditioned reflex secretion of saliva from the stimulation of the skin by cold — are comparatively simple, as compared with many other actions of daily life, such, for example, as the throwing of a stone. Here not only muscles which produce motion at the shoulder, elbow, wrist, and finger joints are called into play, but also muscles which maintain the erect position and balance of the body as a whole. The entire nervous mechanism involved baffles the imagination to conceive; and yet any boy can perform the act. He can do it, however, because his motor neurones are grouped together into a perfectly well-organized army which executes at once the bidding of its commander in chief — the will.

We have given in the foregoing pages a mere glimpse into the complexity of one part of the wonderful nervous mechanism. No watch, no machine which man has ever invented or constructed can for a moment compare with this living machine in complexity or in perfection. Yet, like all machines, this one can be abused; it can get out of order; it can even break down. And we have already learned enough to understand why this is so. Some neurones may be injured by overwork or may degenerate from disuse; indulgence in stimulants or narcotics may poison the governing nerve cells; above all, constant failure to lead a normal life may deprive these cells of their sole means of repair. The human body is a machine designed for use, even for hard use, and it thrives upon right use; but it is a machine too delicate and too complex to be abused with impunity.

When one thinks of the hundreds, perhaps thousands, of movements which the body makes, and of the combination of these movements into definite actions or work, and then reflects that the muscle fibers which execute any movement are thrown into orderly contraction by nerve cells which are themselves commanded by higher nerve cells; that these in turn are marshaled, as it were, by still higher cells when the separate movements they evoke are to be combined into a still more complicated action — one begins to appreciate the complexity of the organization of the nervous system. The number of the nerve cells is measured by hundreds of thousands, and their efficiency in directing the working organs of the body, so as to meet the demands of life, depends not only upon the integrity of the neurones but also upon the perfection of their organization, that is, their grouping into squads, companies, regiments, brigades, divisions, and corps, ready to yield instant and obedient response to the command of the higher officers of the will or to the signals of those pickets — the sense organs and their afferent neurones — which everywhere guard the outposts and give information of the need for action.

Moreover, this army of neurones, like any other army, becomes efficient by work, by drilling, by practice, even by battle. Like the soldiers of a regular army the neurones may be overworked and their efficiency as a military body may suffer thereby, but they may also work too little; the perfection of their development and of their organization depends on the practice they get with reasonable activity. To this point we shall return; but meantime the student can safely make the application for himself. Such comparison and such application are not only instructive but intensely practical in their bearing upon the affairs of everyday life — upon that right conduct of life which is the first duty of every man, every woman, every child.

17. Stimulation and coördination by chemical means; hormones. In previous chapters we have dealt chiefly with examples of stimulation of muscle and gland cells by nervous impulses and of the coördination of the work of organs through the central nervous system; but there is another way by which both stimulation and coördination are effected. An irritable cell will respond to other stimuli than nervous impulses; among these are a sharp blow, sudden heating, make or break of an electric current, and exposure to the action of certain substances. The last is generally spoken of as *chemical stimulation*, and we shall meet with examples of this in our subsequent study. One will suffice for the present. After the food has undergone a preliminary digestion in the stomach by the *acid* gastric juice, it is passed into the small intestine, where its digestion is completed. The first requisite for this purpose is the secretion of pancreatic juice, and this is secured as follows: the acid of the stomach contents liberates from the lining cells of the first part of the intestine a substance known as *secretin*, which enters the blood and chemically excites the cells of the pancreas to secrete pancreatic juice. By this means the pancreatic juice is secreted into the intestine at precisely the time that it is needed there; that is, as each consignment of acid food is discharged from the stomach (see Chap. VIII, p. 113). A substance thus liberated in one organ and stimulating another organ to activity at the time when such activity is needed is known as a *hormone* (Greek *hormao*, "I arouse").

The action of secretin evidently presents, in addition to its feature of stimulation, an element of purposeful coördination, since it insures the proper coöperation of the stomach and pancreas in the work of digestion; and other examples of the same thing might be cited. We have, however, only to refer the student to the case of adrenaline, already described in Chapter VI, for the most striking example of coördination produced by chemical means.

Coöperation, adjustment, and coördination are thus brought about in the body by two means: first, through the chemical action of hormones; and, second, through the mechanisms of the central nervous system. The first provides for situations where no great delicacy of adjustment is required; in the secretion of the pancreatic juice, for example, it is not necessary that a definite quantity, no more and no less, be secreted; in such a muscular movement as writing, on the other hand, it is necessary that each muscle taking part shall act in a very exact manner. For such coördinations the action of the nervous system is generally necessary. Finally, as suggested by our consideration of the conditioned reflex, the nervous system is the chief means whereby we can acquire new mechanisms of coördination, thereby increasing our power of adjustment to new conditions of life.

CHAPTER VIII

ALIMENTATION AND DIGESTION

A. The Supply of Matter and Power to the Human Machine

1. Power and the materials for repair supplied separately to lifeless machines. Living and lifeless machines are alike in that worn-out parts must be renewed and that power must be supplied to do work. In the lifeless machine these two requirements are supplied separately. A factory and its equipment of machinery are kept in repair and enlarged (grow) by means of bricks, lumber, steel, belting, new pieces of machinery, etc., which are brought into the building, while the power which runs the machinery comes in quite separately as fuel, or water power, or electric power.

2. Power and the materials for growth and repair supplied to the human machine in the one form of foods. With the human mechanism this is not so. Materials for growth and repair, and power for running, are introduced from without not separately, but together, both being supplied in the one form of food. As it does its life work the human mechanism, like a lifeless machine, not only consumes power but its parts deteriorate, and it is the double function of the food we eat to make good this double loss. Some foods possibly serve only as means of power; others merely make good the loss of essential parts of the mechanism; while still others may serve both purposes.

3. Food as a source of power. Experiment and experience alike prove that foods are the source of power for work. Bread, butter, starch, sugar, beef, and the like may be dried and then burned as fuel, giving power to an engine. The occasional use of Indian corn or wheat for fuel, in the West, the employment of hams and bacon as fuel by steamers short of coal, the explosion of flour dust in mills, and similar phenomena further illustrate by the teachings of experience the fact that these foods are rich in energy, or power.

When we say that the food must supply power to the body, we mean that the power which it contains *must be available* to the body. A lump of coal may be a source of power, as is shown by its use in a locomotive; but a lump of coal would be of no use as food, because the body has no such means of burning it as has the engine. Again, nitroglycerin contains chemical elements needed in the food; but although when exploded in a dynamite cartridge it may furnish power enough to shatter heavy armor plate, its energy is not available to the body.

Thus, to recapitulate, (*a*) food makes good the loss of living substance in the body; (*b*) it supplies material for growth and for the manufacture of the secretions of the body; and (*c*) it supplies power for the work which the body is to do. It also performs one more important function, which will be more clearly understood hereafter; for (*d*) by its oxidation food provides the heat usually required to keep up the body temperature. The detailed consideration of this subject, however, must be postponed to Chapter XII.

4. Chemical composition of foods; nutrients. The human race has learned by long experience that certain things meet the demands of the body for food, and that other things do not. Perhaps no animal uses so many different materials as man in satisfying sensations of hunger and thirst. Some foods are taken from the animal and some from the vegetable kingdom, and their variety is greatly increased by special modes of preparation. But however numerous the foods from which we prepare the dishes served at different meals, chemical analysis shows that the essential constituents of all foods belong to a comparatively small number of chemical groups. These classes, or groups, may be called *nutrients*; and as all the members of the same group undergo practically the same processes of digestion and perform similar functions in nourishing the body, it will be equally accurate and more convenient, in treating of this part of physiology, to speak of the different nutrients, and not of beef, mutton, fish, eggs, bread, milk, butter, etc.

From the point of view of digestion the most important nutrients are the *proteins*, the *carbohydrates*, the *fats*, the *inorganic salts*, and *water*; and the student must at this point become thoroughly familiar with what is meant by these fundamental terms.

5. The group of proteins. We may obtain a working idea of what a protein is by recalling some of the foods in which protein preponderates or is easily seen. Such foods are the white of egg, the lean of tender meat (muscle fibers), the curd of milk, the tenacious gluten of wheat. Proteins also exist in relatively large quantities, though not so readily seen, in yolk of egg, beans, peas, oats, and other grains.

Proteins contain carbon, hydrogen, nitrogen, oxygen, and sulphur. Some contain phosphorus and some contain iron. Chemically they are exceedingly complex substances. It should be noted that the proteins are the most important nutrients which contain *nitrogen* and *sulphur*.

Many proteins readily become insoluble. Examples of this are the hardening of the white of egg or the lean of meat by cooking and of the casein or curd of milk by rennet or "junket tablets." This change is known as *coagulation*, and most of our protein food is eaten after having been coagulated in the process of cooking.

Proteins occur only within the living cells of plants and animals or as the products of these living cells. They form, as we shall more clearly see later, an essential part of the basis of the living cell and are constantly disintegrating within the cell into simpler substances. Hence there is a constant cellular loss of protein, which in the animal body can be made good only from protein in the food. Plants, on the other hand, have the power of manufacturing proteins from sugars and certain mineral salts, the latter supplying the needed nitrogen and sulphur. The plant kingdom is, therefore, in the long run the sole source of protein food for animals; for while some animals (*carnivores*) get their protein entirely by eating the flesh of other animals, the latter (*herbivorous animals*) in turn have obtained their protein from plants.

Unlike fats and carbohydrates, protein is an absolute essential of animal diet; that is to say, protein food performs certain functions in the animal body which cannot be performed by fats or carbohydrates, while the two latter nutrients perform no functions which cannot also, when necessary, be met by proteins. Some proteins, however, are incapable of meeting all the protein requirements of the organism, although they may meet some of them. Of these the most important in use as food is the fibrous connective tissue (pp. 7, 8), whose fibers in the uncooked state consist of the insoluble protein substance *collagen*, which by heating in the presence of water is converted into the closely related but soluble *gelatin*. Collagen and gelatin belong to the **albuminoids,** one of the subclasses of proteins. The chief protein of Indian corn is similarly incapable of meeting all the protein requirements of the organism.

6. The group of carbohydrates; the plant cell as a food factory. The carbohydrates constitute a very large chemical group, although comparatively few members of it (starch and sugars) are of importance as food. They are all compounds of the elements carbon, hydrogen, and oxygen, and contain no nitrogen or sulphur; those used as food are manufactured in the cells of green plants. This production of carbohydrates by the plant cell is another example of the work of cells as chemical factories, which we studied in Chapter IV. The cells of the green parts of plants, especially of the leaves, take in carbon dioxide from the air and water from the soil, and from these plant foods, with the aid of sunlight, manufacture *sugar*, which is transported in the sap from one part of the plant to the other and is used as a source of power for plant work. The excess of sugar is converted by certain cells into *starch* and is stored in the form of small granules in the cytoplasm for future use. A potato or a grain of wheat consists of cells loaded with these starch granules. When the plant is not manufacturing sugar directly from carbon dioxide and water, its cells again transform the starch granules into sugar. The presence of sugar in sugar beets, apples, pears, and peaches and in the sap of sugar maples are familiar examples of this manufacture and transport of sugar by plants.

It will be noticed that only green plants have this power of manufacturing carbohydrates from carbon dioxide and water; hence we do not find large quantities of sugar and starch in mushrooms and other fungi. The cells of green plants, in short, are the starch factories of the world, the factories from which we purchase our supplies of starch being only refineries, that is, places where starch is separated from other constituents of plant cells.

All plants, however, possess the power of manufacturing proteins from carbohydrates and certain salts, which salts they get from the soil. The carbohydrates furnish carbon, hydrogen, and some of the oxygen, while the salts furnish nitrogen, sulphur, phosphorus, etc. One great difference between plants and animals is this power of protein manufacture by the cells from material which is not protein. The animal cell can manufacture protein only from protein itself or from certain decomposition products of protein.

7. The group of fats. Fats are familiar to us in such forms as butter, lard, olive oil, and the fat of meat. Like the carbohydrates they are compounds of carbon, hydrogen, and oxygen, although the oxygen is always present in small quantities. The formula for one of the fats is $C_{51}H_{98}O_6$, and this composition is typical of all of them.

Fats may be split up into certain acids (*fatty acids*) and *glycerin*, and when treated with alkalies, like caustic soda or caustic potash, they form *soaps*. They are insoluble in water. Like the carbohydrates they contain *no nitrogen*.

8. Oxidizable and nonoxidizable nutrients. All the above nutrients may and do combine with oxygen within the cells of the body, although the way in which this chemical union is brought about is one of the unsolved problems of physiology. While all the nutrients may be burned after being dried, such combustion requires a high temperature. Within the body they are not only burned (that is, combined with oxygen) at a temperature rarely exceeding 39° C. (100° F.), but they undergo oxidation while in a moist state or even in solution. However this oxidation may be effected within the cell, there can be no doubt that it yields the heat for keeping the body warm and possibly the power for its work.

The remaining groups of nutrients — the inorganic salts and water — are, for the most part, not oxidized in the body.

9. The groups of inorganic salts and water. These nutrients are absolutely necessary for the proper nourishment of the body, their presence in the blood and lymph and in the living cells being indispensable to the processes of life. The salts are taken in small quantities, partly as salt itself, partly as portions of the various foods we eat. During growth they furnish much of the mineral matter of bones, and since the body is daily losing salt, it is necessary that salt be supplied in the food. Salts, however, are not acted on to any large extent in the alimentary canal by the processes of digestion; they are largely absorbed in the same form as eaten. Hence they do not concern us at present to the same extent as do the oxidizable nutrients, which generally have to be chemically changed, or *digested*, before they can be absorbed for use in the body. The same thing is true of water.

10. Composition of some common foods. The following table gives the percentage composition of some of the more common foods (see also p. 238).

	WATER	PROTEIN	STARCH	SUGAR	FAT	SALTS
Bread	37	8	47	3	1	2
Wheat flour	15	11	66	4.2	2	1.7
Oatmeal	15	12.6	58	5.4	5.6	3
Rice	13	6	79	0.4	0.7	0.5
Peas	15	23	55	2	2	2
Potatoes	75	2	18	3	0.2	0.7
Milk	86	4	—	5	4	0.8
Cheese	37	33	—	—	24	5
Lean beef	72	19	—	—	3	1
Fat beef	51	14	—	—	29	1
Mutton	72	18	—	—	5	1
Veal	63	16	—	—	16	1
White fish	78	18	—	—	3	1
Salmon	77	16	—	—	5.5	1.5
Egg	74	14	—	—	10.5	1.5
Butter	15	—	—	—	83	3

11. Indigestible material in food. When we say that a food is digestible we generally mean that when taken into the alimentary canal, if not already in solution, it is chemically acted upon by the digestive juices so as to be *dissolved* and made capable of being *absorbed* into the blood. The greater part of the food we eat consists in this sense of digestible substances, but many foods contain a certain amount of indigestible material, and some contain a very considerable amount.

The most conspicuous example of such material is *cellulose*, a member of the same group of carbohydrates to which starch belongs. It occurs in almost all vegetable foods; and since, in the human alimentary canal, cellulose is for the most part unaffected, it cannot be absorbed and necessarily forms an important part of the feces. Other indigestible substances are the outer skin of animals (for example, the skin of fowls), and certain portions of the connective tissue of meat.

12. Animal and vegetable foods. The classification of foods into animal and vegetable not only describes the origin of foods from the two great kingdoms of living things, but also defines important differences between them with reference to digestion. These differences may be summed up as follows: Animal foods are generally rich in proteins and poor

FIG. 51. Part of the seed of the bean
Showing the larger starch granules and the finer protein granules inclosed within the cellulose cell walls

FIG. 52. Section of potato
Showing starch granules inclosed within the cellulose cell walls

in carbohydrates, while vegetable foods are generally poor in proteins and very rich in carbohydrates, especially starch. In the second place, animal foods contain relatively little indigestible material, while vegetable foods, as they occur in nature, contain large amounts of indigestible cellulose. In the third place, the digestible materials of vegetable foods (the proteins, carbohydrates, and fats) are often contained within a plant cell which is surrounded by a cellulose membrane impermeable to the digestive juices; before they can be digested this membrane must be ruptured in one way or another. In the case of many animal foods, on the other hand, especially meat and fat, the cells (muscle fibers and fat cells) which contain the essential nutrients are held together by connective tissue made up largely of fibers of an albuminoid nature. These fibers are soluble in the juices of the stomach, in which the cellulose which holds together the vegetable foods is insoluble. The full importance of these differences will be evident before we have finished the study of digestion.

13. The process of alimentation. Before corn, wheat, meat, vegetables, and other food materials can be taken into the body and made to yield up to it the material and power which they contain, they must, in most cases, undergo various preparatory or preliminary processes or treatments which shall make them easier or better to eat or more attractive. The most familiar of these processes is cooking, but it is by no means the only one. In the case of animal food the animal must be captured, if wild, or raised, if domesticated. It must be killed, skinned, dressed, cut up, and the meat in many cases "ripened" by keeping, or "cured" by smoking, salting, drying, or corning. So, also, with plant food, such as cereals, vegetables, fruits, nuts, and the like; these must first be found, if wild, or grown, if domesticated. They must then be separated from the rest of the plant — threshed, if wheat, rye, oats, or barley; husked and shelled, if corn; dug up or removed from the earth, if vegetables like potatoes, celery, radishes, or lettuce. Fruits and nuts must be separated or picked from vine or tree; milk must be drawn from animals; and even salt, water, and condiments like mustard and pepper must be separated from the earth or the sea or from plants. After collection and further preparation by winnowing, grinding, or cleaning, elaborate cooking is applied to many forms of food before it is put upon the table; and even then, at the last moment before it is eaten, a further separation, as of meat from bone, must be made either by the carver or by the eater himself.

To this entire process of the supply and preparation of food for eating, the term "alimentation" may be conveniently applied. Reflection will show that it is largely a process of *food refining*, the principal result being a concentration of the nutrients at every step. It is also a separation of the comparatively useful from the comparatively worthless (as food); and just here, and in these points, — *concentration* and *the separation of good from poor materials*, — we may recognize a true process of digestion, but one external rather than internal: a refining in the field, the mill, and the kitchen rather than in the stomach; in the environment rather than within the organism.

14. The ends accomplished by digestion. The processes of digestion accomplish three chief results: First, they separate the nutritious and therefore important part of the food from the innutritious and therefore useless. This process, so conspicuous in the case of external digestion, is continued within the alimentary canal. Second, digestion brings the solid part of the food into solution by changing insoluble into soluble substances. This is necessary, since food is received into the body proper (that is, into the blood) through the lining membranes of the alimentary canal, and in order that it may pass through these membranes it must be dissolved. In the third place, digestion transforms the food as eaten into compounds which can be used by the cells of the body. Common cane sugar, for example, is very soluble and can be absorbed into the blood, but the cells of the body cannot use it. In the intestine it is split into grape sugar and fruit sugar, both of which can be used. Similarly, the white of egg (a protein), though soluble, would be of little, if any, use if injected unchanged into the blood; in the alimentary canal it is transformed into available compounds. It will be helpful to acquire at this time a general idea of the chemical structure of two of our most important foods and of the chemical changes which they undergo in the alimentary canal.

15. The chemical structure of the starch and protein molecules; cleavage changes during digestion. The huge molecules of starch and protein are believed by chemists to consist of a large number of much smaller molecules linked together

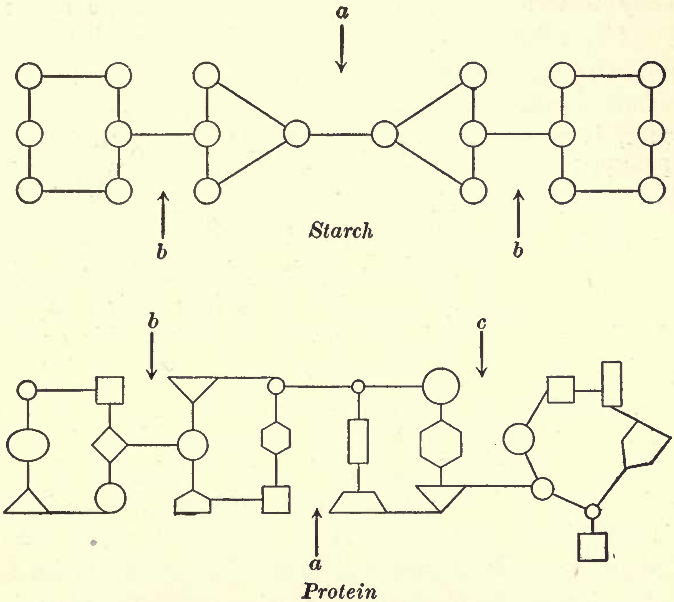


FIG. 53. Diagram of the structure of molecules of starch and protein

Starch is represented as formed by the chemical linking together of many like molecules of dextrose; protein, by the linking together of many unlike molecules of amino-acids. Some of these chemical links (indicated by the arrows) are broken by cleavage more easily than others. Hence cleavage first forms smaller molecules of dextrines from starch and of polypeptids from proteins. Ultimately each may be broken up into its constituent molecules of dextrose or amino-acids respectively

in chemical combination (see Fig. 53). By boiling in water containing acid, these large molecules undergo a very simple cleavage into their component molecules. Starch treated in this manner yields only one substance, namely *dextrose* (*glucose*, or *grape sugar* ($C_6H_{12}O_6$)). Protein, on the other hand, yields a much greater variety of compounds, some twenty or more in number, which, though differing greatly from one another in most respects, have in common one point of structure in virtue of which they are known as *amino-acids.* In the chemical laboratory amino-acids are readily bound together to form *peptids*, and we speak of dipeptids, tripeptids, tetrapeptids, and polypeptids according as two, three, four, or many amino-acids enter into their formation. It is now thought that protein, as it occurs in nature, is essentially a very complex polypeptid.

In the body the enzymes of the digestive juices produce virtually the same cleavage in starch and protein as that caused by boiling with acids, and the chemical action upon the food within the stomach and intestine consists essentially in breaking up the starch and protein into their component molecules — dextrose in the one case, amino-acids or small peptids in the other. We accordingly find that as the result of digestion the starch we eat supplies the blood (and so the body cells) with only one substance, namely dextrose (grape sugar), and the value of starch in nutrition is limited to the nutritional value of *this single substance*, dextrose, of which it is composed. Protein, on the other hand, yields twenty or more different chemical compounds, each with its own possibilities of chemical action in the cell. Moreover, individual proteins differ in their constituent amino-acids; a given protein may be entirely lacking in one or more amino-acids, or it may have one or more present in very small or very large proportions. The nutritional value of the protein is consequently determined by the possibilities of chemical action of its constituent amino-acids and by the quantity of each amino-acid yielded by the digestive cleavage. From this we can readily understand why protein food meets a wider variety of nutritional requirements than does starch or fat, which also yields only a few cleavage products upon digestion.

16. Digestion a chain of events. Before entering upon the study of the details of digestion in the different parts of the alimentary canal, a suggestion as to the proper point of view will be helpful. While it is true that each part of the digestive system performs functions of its own, it is also true that what takes place in one part is dependent on what takes place in others; digestion in the mouth has reference largely to subsequent work in the stomach; gastric digestion, in turn, carries one step further the refinement of the food, which it thereby prepares for what is to take place in the small intestine; finally, the digestive processes of the large intestine are carried out normally only when preceded by the proper completion of those of the small intestine. Digestion is *a chain of events*, each one depending upon those which have gone before and, to a large extent, upon others which are taking place at the same time. The student is urged to keep this in view in the study of all the digestive processes.

B. Digestion in the Mouth. Enzymes

17. Stimulation of the sense of taste a reflex excitant of the flow of gastric juice. Digestion in the mouth prepares for digestion in the stomach, in the first place, by stimulating the sense of taste through the flavor of the food, for the afferent impulses thus aroused play a very important rôle in evoking the secretion of gastric juice. This point will be more fully discussed in our studies of gastric digestion. It is referred to here that the student may understand that far more is to be accomplished by the stay of food in the mouth than its mastication and mixture with saliva preparatory to the act of swallowing. We might imagine a meal composed of food already well moistened and requiring no chewing, so that it could be swallowed immediately. Such a meal might have all the nutrients in the proper proportions, and yet, from the very fact that it stays so short a time in the mouth, it may not sufficiently arouse sensations of taste to evoke an adequate reflex secretion of gastric juice. It is perhaps here that we have the strongest argument against hasty eating.

18. Mastication. Digestion in the mouth prepares for digestion in the stomach, in the second place, by the comminution, or grinding down, of the food in the act of chewing. When this is properly done the larger food masses are broken up into smaller ones, so that the whole is made more readily accessible to the subsequent action of digestive secretions. The small intestine has almost no means of accomplishing this subdivision of the food; the stomach can do it for some foods easily, for others with difficulty, while against others it is virtually powerless. Only in the mouth can all foods be thoroughly comminuted. For this purpose it is necessary to keep the teeth sound.[1]

19. Chemical action of saliva. Digestion in the mouth presents a feature which is characteristic of all the digestive processes; namely, a combination of the mechanical action of some form of muscular movement with the physical and chemical action of some digestive juice. The muscular act of chewing and the secretion of saliva, which moistens and acts chemically upon the food, coöperate to reduce the food to smaller particles and to change part of it into other substances. Neither mastication nor insalivation, acting alone, would be as effective as are both when acting together. We shall see the same thing more strikingly illustrated in our studies of gastric and intestinal digestion.

The chemical action of saliva is much less important than that of other digestive juices, but it is typical of the character of all of them, so that it is profitable to consider it at some length. Upon proteins and fats saliva has no action whatever, but upon starch it exerts a striking and readily demonstrable influence. To demonstrate the effect in question some starch paste should be prepared. This is not a

[1] The structure and care of the teeth will be described in Part II, Chap. XXIII.

clear solution, like salt or sugar, but an opalescent liquid, which does not become clear by passing through ordinary filter paper. A characteristic test for starch — the blue color produced when a few drops of a solution of iodine[1] are added to it — may be used to detect its presence in the following experiments:

EXPERIMENT I

Two test tubes or small beakers containing starch paste are prepared. Collect some saliva and boil half of it. To one portion of the starch paste add the boiled saliva (after it has again cooled to the room temperature); to the other add the unboiled saliva. Mere observation will show that while the first test tube remains opalescent, the second soon becomes clear. A few minutes after this change has occurred, a little of the second starch-saliva mixture may be removed, diluted with water, and tested with iodine; the color produced is no longer pure blue, but purplish; that is, a mixture of red and blue. Some minutes later the iodine test gives a port-wine red color, and still later no color at all. This change of reaction is due to the fact that the saliva has changed the starch into dextrine, which gives the red color, and then has changed the dextrine into a substance which gives no color with iodine.[2] Meanwhile the starch in the first test tube shows no change either in its opalescent appearance or in its original blue reaction with iodine.

Boiling the saliva has destroyed its power of acting on starch, and it is known that this is due to the fact that the heat has destroyed the enzyme, known as ptyalin, or salivary diastase, which has the power of changing starch to sugar.

[1] Made by dissolving a few flakes of iodine in alcohol or in an aqueous solution of potassium iodide.

[2] The cleavage of the starch molecule does not take place by splitting off successive molecules of dextrose, but by splitting into two molecules, each, let us say, approximately half as large as the original molecule. By some such process first one, then another, dextrine successively appears. Continuation of the cleavage ultimately gives a substance, *maltose*, which consists of two molecules of dextrose bound together. Finally, the maltose is split into two molecules of grape sugar. We speak of the dextrines and maltose as *intermediate products*, and of the dextrose as the *end product*, of the cleavage.

EXPERIMENT II

Let us now inquire what has become of the starch in the second test tube. The solution is clear and has a sweetish taste. Moreover, if boiled with a mixture of sodium hydroxide and a few drops of copper sulphate, it gives a red precipitate, indicating the presence of sugar. These simple tests then prove that saliva first changes starch into dextrine and subsequently changes dextrine into sugar.

EXPERIMENT III

Dilute some starch paste with an equal volume of 0.4 per cent hydrochloric acid (which will, of course, make a 0.2 per cent solution of the acid). Now add a few drops of saliva. It will be found that no reaction takes place. Saliva will not act in an acid medium of this strength, and it can be easily shown that it acts most vigorously in a neutral or faintly alkaline medium. This result is of much practical importance, because the gastric juice contains approximately 0.2 per cent of hydrochloric acid and may therefore be expected to interfere with salivary digestion.

EXPERIMENT IV

Prepare five or more small beakers of starch paste and add (best with a medicine dropper) to the first a drop of filtered saliva, to the second two drops, to the third three drops, and so on; then observe the time required in each case for the disappearance of the opalescence and also of the iodine reaction. This experiment will show that while a very small amount of saliva will transform an indefinite amount of starch into sugar, the more saliva there is present the more rapidly will the transformation occur; and the same thing is true of all enzymes. If the result is not perfectly clear with the undiluted saliva, repeat, but use saliva diluted two or three times with water.

While we are eating, the food obviously stays too short a time in the mouth to allow the conversion of any large amount of its starch into sugar before it is swallowed. Whatever actual work the saliva may do in bringing about this chemical change must evidently be done chiefly in the stomach, and this will be studied in the next section.

We have dwelt at length upon the enzyme action of saliva not merely for its own sake but rather because the behavior of the salivary juice is typical of the action of other of the digestive juices and of enzyme action in general. All the other juices of the alimentary canal, with the single exception of the bile, contain enzymes, and it will greatly help our understanding of the digestive action of these enzymes if that of the salivary enzyme be first mastered.

Digestion in the mouth, then, consists first, of a mechanical process of chewing, by which food is crushed or comminuted; second, of a physical process of moistening, by which dry foods are prepared for the act of swallowing; and third, of a chemical process, the chief part of which is the conversion of starch into sugar by enzyme action. In addition to this the stimulation of the sense of taste reflexly starts the secretion of the gastric juice, which now becomes the main chemical agent in carrying on the work of digestion. To the consideration of the digestive processes in the stomach we may now devote our attention.

C. Digestion in the Stomach

According to popular ideas the stomach is the chief organ of digestion; in fact, however, it is an organ in which the food which has been swallowed is temporarily stored while undergoing a preliminary preparation for the more important changes which are to take place in the intestine. In this preparatory process, to be sure, some of the food is incidentally changed into those forms in which it passes into the blood, but this action is incidental and subordinate to the main function.

20. Form and structure of the stomach. The stomach is a large pouch into which open two tubes — the œsophagus (gullet) toward the left side and the intestine on the right (see Fig. 54). The two regions into which these tubes open are different in structure and are known as the *cardiac* (left) and *pyloric* (right) portions of the stomach; the cardiac portion differs from the pyloric portion in having greater diameter and thinner walls. The entire inner surface is lined by the *mucous membrane* some three or more millimeters in thickness, crowded with comparatively simple glands which pour their secretion, the *gastric juice*, into the stomach very much as sweat glands discharge perspiration on the skin (see Fig. 55).

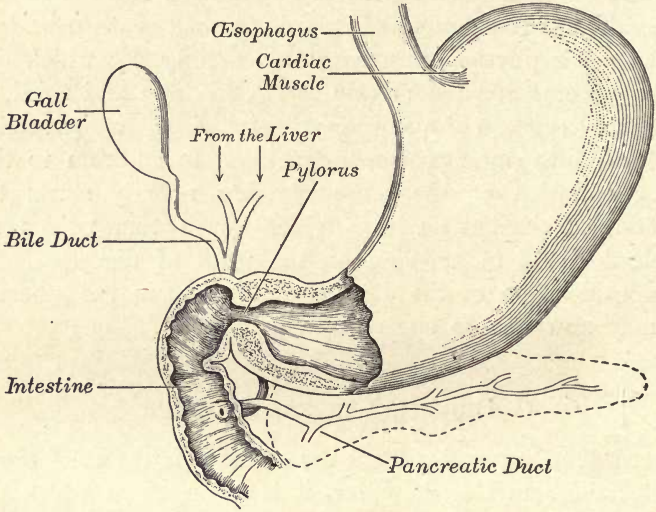


FIG. 54. Stomach, beginning of small intestine, and entrance of bile and pancreatic ducts

During digestion the bile flows directly from the liver into the intestine; at other times the opening of the bile duct is closed and the bile passes into the gall bladder, where it is stored

The glandular membrane is one of the two principal components of the stomach wall; the other is the muscular or contractile tissue, which forms a second coat outside the other, and closely united to it by connective tissue containing the larger blood vessels, lymphatics, nerves, etc.[1] The muscular coat is comparatively thin in the cardiac region

[1] Fig. 63 (large intestine) shows in cross section somewhat the same arrangement of mucous and muscular coats as in the wall of the stomach.

and comparatively thick in the pyloric, the thickening in the latter region being caused chiefly by muscle fibers circularly arranged.

21. The gastric juice. The gastric juice is a clear, thin, colorless liquid which contains, among other things, about 0.2–0.3 per cent of hydrochloric acid and certain enzymes. Upon starch it has no action whatever, nor has it any action on fats, unless the fat is in the form of an emulsion (that is, very fine drops of oil suspended in water, as in milk or mayonnaise dressing); indeed, the very limited power of gastric juice to attack fat is a matter of considerable importance in dietetics. Its main chemical action is upon the proteins, which under its influence undergo cleavage into *proteoses* and *peptones*. The proteoses and peptones, like the original protein, are polypeptids (p. 102), but of smaller molecular size. They are not coagulated by heat, and most of them are soluble.

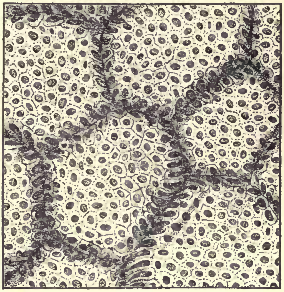


FIG. 55. The inner surface of the stomach (magnified about 20 diameters)

Showing the openings of the glands. The lining glandular membrane is thrown into folds

EXPERIMENTS

Prepare some artificial gastric juice as follows: To one quart of water add 7 or 8 cc. of concentrated hydrochloric acid and to this a little active pepsin, which may be obtained at any drug store. Pepsin is extracted from the stomach and is the most important of its enzymes. A solution of pepsin in the given strength of hydrochloric acid is virtually gastric juice. Try the effect of this on the following substances by placing each in a half tumblerful of the juice. To get the complete effect the mixture should be set aside for twenty-four hours and tests made the next day. Observations should be made during the first hour or two. If the digesting mixture can be kept in a warm place (90°–100° F.), the action will be more rapid and the results more satisfactory. The digestions can best be carried out in corked 4-ounce bottles, which should be shaken occasionally to secure better contact of the digestive juice with the material undergoing digestion.

1. The white of soft-boiled (3-4 minutes) egg. This is composed mostly of protein; it will be dissolved. Into what is the egg white changed?

2. A piece of tendon, which can be obtained from any butcher. This is composed of the kind of fibers which are found in the connective tissues holding the cells together (see Chap. III). The tendon first swells, then gradually disintegrates, its protein (albuminoid, p. 94) fibers going into solution. A small residue will be left.

3. A piece of the lean of rare meat cut or chopped into small pieces. The meat will disintegrate, owing to the solution of its connective tissue fibers; then the protein muscle fibers will go into solution, being changed into soluble peptids.

4. A piece of lean of well-cooked meat. The result will be much like that in (3) except that it will probably take longer to bring the muscle fibers into solution.

5. Some jelly (made from gelatin) which has set. This will be gradually dissolved.

6. Some fat (not gristle) of beef. The mass will disintegrate for the same reason as in the case of meat. The fat itself will be unacted on, but will rise to the top, where it may form a layer of fat or oil.

7. A piece of bread. This consists of starch, fat, etc. held together by the tenacious gluten (a protein). As the gluten is dissolved by the gastric juice the undissolved starch, fat, etc. is set free.

8. Some starch paste. No action.

9. Some fried steak. Note the prolongation of the period of digestion.

Instructive experiments may also be made with cheese, sweetbreads, potatoes, peas, etc. They would all bring out the main points in the action of the gastric juice. These may be summed up as follows: Gastric juice has no effect upon pure fats (although it plays an important part in the digestion of adipose tissue[1]), nor upon carbohydrates, such as starch or sugar. Its part in digestion consists in its action

[1] The fat of meat consists of connective tissue whose cells are greatly swollen with drops of fat. In typical adipose tissue the connective-tissue cell becomes one large fat droplet surrounded by the thin layer of the cell cytoplasm with its nucleus. These "fat cells," like the muscle fibers of meat, are thus held together by the fibers of connective tissue and are set free when the latter are digested and dissolved away by the gastric juice (see Figs. 90-92).

upon the proteins of the food and especially upon those proteins (albuminoids) which make up the connective tissue of animal foods. By dissolving this connective tissue, which holds together the muscle fibers, fat cells, etc., animal food is considerably subdivided and made to present a greatly increased surface to the further action of digestive juices. It is also well to remember that the gastric juice dissolves connective tissue much more rapidly than does any other of the digestive juices and that this action upon connective tissue is really more important than that upon other proteins, although the latter is usually more emphasized. Other proteins not acted on in the stomach are rapidly digested by the pancreatic juice in the intestine; connective tissue, on the contrary, escaping solution in the stomach, is dissolved but slowly in the intestine.

The student is, however, warned against supposing that because gastric juice is able to transform the proteins of the food to peptids, it actually does exert this action upon all the protein eaten. In point of fact, as protein foods are divided into smaller and smaller particles in the stomach, they are discharged into the intestine, where their digestion is completed by the pancreatic juice. *In man the pancreatic, and not the gastric, juice is the main agent of protein digestion.*

22. The stomach at work. Having now gained a general idea of the chemical changes which occur in the stomach, we may proceed to consider what actually happens when food enters that organ. And here our knowledge has been gained partly by examining the gastric contents at different periods of digestion, partly by observing the movements of the stomach by the aid of the Röntgen rays, and partly by other means.

As soon as food enters the stomach, and even while it is still in the mouth, the gastric glands begin to discharge the gastric juice, and continue to do so during the four or more hours of gastric digestion. When the meal is fluid or is small in amount, this gastric juice is thoroughly mixed with it; when, however, the food is more or less solid and bulky, only the outer layers, which are in immediate contact with the walls of the stomach, are mixed with the juice. At least this is true at the cardiac end; the cavity of the pyloric portion is so small and the amount of movement there so great that all portions of the pyloric contents are thoroughly mixed with gastric juice; in the much larger cardiac portion the central mass of the food may receive no gastric juice and thus remain, for an hour or more after the meal, neutral or alkaline in reaction. Under these circumstances very considerable amounts of starch may continue to undergo the salivary digestion begun in the mouth.

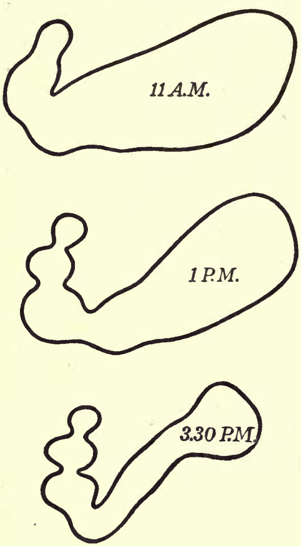


FIG. 56. Outline of the contents of the stomach of a cat at three stages of the digestion of a meal taken about 11 A.M.

Showing the peristaltic constrictions which pass over the pyloric portion and the diminution of the quantity of food in the cardiac end. (Full description given in sect. 22)

Any chemical action is aided by agitation, since the reacting compounds are thus brought into more intimate union; and observation of the working stomach shows that while the cardiac portion makes no movements, but merely keeps up a steady contraction and thereby exerts a moderate pressure upon its contents, the pyloric portion executes, from a very early stage of digestion and throughout the whole process, a series of contractions which gradually bring about a thorough mixture of the contents and rub down the softened food into smaller and smaller masses. These contractions consist of rings of constriction which arise at the beginning of the pyloric portion and pass onward to the pylorus itself, a new ring beginning about once every ten seconds and consuming from thirty to forty seconds in passing to the pylorus. Consequently there are always two or more slowly moving rings in the pyloric end of the stomach at one time.[1]

The pyloric end of the stomach is thus the seat of a combined chemical and mechanical action on the food. The vegetable foods are softened, while the connective tissue of the animal foods is dissolved away; in addition, the food is mixed with a considerable amount of liquid supplied by the secretion of gastric juice. The contents of the pyloric end of the stomach thus ultimately come to consist of *minute solid masses suspended in a liquid*, the consistency of the whole being that of moderately thick pea soup. This product of the work of the stomach is known as *chyme.*

23. The expulsion of chyme into the intestine. The openings of the œsophagus and intestine into the stomach are usually closed; the former is opened normally only during the act of swallowing, while the latter opens at irregular intervals during the process of gastric digestion. The opening of the pylorus allows the rings of constriction moving over that region of the stomach to discharge the semifluid chyme into the intestine. If, however, a large mass of solid food arrives and is driven against the walls, the pylorus reflexly closes, thus guarding the entrance of the intestine from the passage of food not yet ready for intestinal digestion. The pressure exerted by the sustained contraction of the walls of the cardiac end of the stomach adds to the food in the pyloric region new portions from time to time, and the same combined chemical and mechanical process already described is continued until the whole mass is reduced to chyme and driven into the intestine.

[1] These movements of the stomach and intestine are well shown in zoetrope figures, which may be obtained from the Harvard Apparatus Company, Back Bay Post Office, Boston.

This brief sketch of the working of the stomach shows that this organ serves the two main functions of storing the food and of making it more accessible to the digestive fluids of the intestine. When the chyme is delivered to the intestine, the mechanical difficulties in the way of absorption are practically gone; the surface of the food exposed to digestive action is now immensely increased by its subdivision, and the work remaining for the intestine is almost wholly the *chemical* duty of changing the constituents of the chyme into substances which are soluble and ready for absorption.

Serious troubles arise when, for one reason or another, gastric digestion goes wrong, because the subsequent processes of digestion are largely dependent upon the preparation which the food receives in the stomach. Gastric digestion may be impaired in one of three ways: first, the gastric juice may not be secreted in proper amount or proper strength; second, the stomach may not execute its movements efficiently; third, the gastric juice secreted may not be able to get at the food readily, owing to improper cooking or insufficient mastication. The study of the conditions which produce these troubles — which taken together constitute one form of *indigestion*, or *dyspepsia* — will be postponed to the chapter on the Hygiene of Feeding (Part II).

24. The stimulus to the secretion of the gastric juice. The first requirement for the work of the stomach is the secretion of sufficient gastric juice. Of late years the brilliant researches of physiologists have shown that the secretion of gastric juice is called forth in three ways:

1. *The "psychic" secretion.* When agreeable or appetizing food is offered to an animal, and especially when such food is taken into the mouth, a secretion of gastric juice follows, which may continue for fifteen minutes or more. This secretion occurs when the food has been in the mouth only ten or fifteen seconds and even when it is merely offered to a hungry animal and not taken into the mouth at all. Again,

it occurs only when the animal is conscious; for if food be introduced into the stomach of a sleeping dog, it evokes only the most scanty secretion of gastric juice after the animal has awakened. Moreover, both the amount and the efficiency of the juice secreted vary directly with the enjoyment of the meal. When meat is given to a dog which is not hungry, no such abundant secretion of gastric juice occurs as during hunger.

It is clear that we have here to deal with a nervous process more complicated than the simple reflex, and that the efferent discharge to the stomach occurs as the result of nervous processes taking place in the brain in connection with the *enjoyment* of food. In other words, the more the food is desired or enjoyed, the more efficient will be this secretion of the gastric juice.

FIG. 57. The curve of the "psychic" secretion of gastric juice

Vertical lines represent half-hour periods after taking the meal; horizontal lines, relative amounts of gastric juice secreted

It is known that this "psychic" secretion will continue for several hours after an ordinary meal, increasing in amount during the first hour or more and gradually diminishing from that time onward (Fig. 57).

2. *Stimulation of the stomach by constituents of certain foods.* We have seen that the direct introduction of food into the stomach (for example, into the stomach of a sleeping animal) does not of itself evoke a secretion of gastric juice. Some foods, however, contain substances which do evoke such a secretion, the most important of these being certain constituents of meat. Bouillon, for example, which is an extract of meat, directly excites the wall of the stomach to secrete.

This is a reason for introducing the soup early at a course dinner. Meat extracts and meat juices are the most effective food constituents for this purpose; milk and water are far less effective, while most foods, notably bread, white of eggs, etc., have no such effect at all.

3. *Stimulation of the stomach itself by the products of protein digestion.* Although the mere contact of most foods with the lining of the stomach does not evoke a secretion of gastric juice, yet it is known that after digestion has been begun by the action of the "psychic" secretion, certain of the products of protein digestion arouse a second secretion by acting directly on the lining of the stomach. This second secretion increases in amount as the first (or "psychic") secretion diminishes, and continues throughout the remaining period of gastric digestion.

To sum up: The secretion of the gastric juice is initiated by a complicated series of nervous processes connected with the enjoyment of the food while it is being taken and masticated; this is aided to some extent by direct stimulation of the lining of the stomach by a few food constituents, notably the extractives of meat. The gastric juice thus secreted acts upon the proteins of the food and produces from them digestive products which directly stimulate the stomach to secrete and, in fact, maintain the secretion to the end of the period of gastric digestion. Without the "psychic" secretion proteins are not digested fast enough to induce sufficient subsequent secretion; without the stimulus of the products of protein digestion the "psychic" secretion does not suffice to complete the digestion of a hearty meal — a labor which may require four or five hours.[1]

[1] What we have called the "psychic" secretion is probably an unconditioned reflex from the mouth, reënforced by a conditioned reflex involving the action of the cerebrum; the stimulation by the products of protein digestion and possibly that by meat extracts, on the other hand, is probably due to a hormone (p. 89) liberated in the mucous membrane of the pyloric region, thence passing into the blood, and so stimulating the gastric glands to secrete.

D. Digestion and Absorption in the Small Intestine and in the Large Intestine

Every few minutes during the process of gastric digestion the pylorus opens and the stomach forces a few cubic centimeters of chyme into the intestine. Chyme, which consists of water holding in solution certain products of digestion, and carrying in suspension larger quantities of undissolved matter, has the consistency of moderately thick pea soup. The suspended matter consists, among other things, of small bundles of muscle fibers (from meat), fat melted by the heat of the body and set free from adipose tissue by the digestion of its connective tissue, bits of coagulated protein, such as casein from milk or the white of egg, together with starches, fats, and proteins of animal or vegetable foods. Thus far the digestive processes in the mouth and stomach have been essentially preparatory to the *main chemical work of digestion, which takes place in the small intestine.* The finely subdivided food is now attacked by the digestive juices of the small intestine brought into solution, and otherwise made ready for absorption into the blood.

25. The general structure of the intestine; the pancreas and the liver. The main functions of the intestine, like those of the stomach, are indicated in the structure of two of its coats, the muscular coat and the glandular mucous membrane. The fibers of the former are arranged in two layers — an inner layer in which they are circularly disposed around the mucous membrane (see Fig. 58), and a much thinner outer layer in which they run lengthwise. The contraction, or shortening, of the circular fibers constricts the bore, or lumen, of the tube, and this constriction of the intestinal tube is the most important work of the muscular coat. Sometimes the constriction is confined to one place; at other times it moves along the tube, pushing before it the contents. (See under Peristalsis, p. 125.)

In the structure of the inner or mucous membrane two points are of importance to us. In the first place, numerous simple tubular glands discharge into the intestinal tube an important digestive juice, the *intestinal juice*; in the second place, fingerlike processes, or *villi* (0.5–0.7 mm. long by 0.1 mm. thick), arise from its surface and project into the intestinal cavity. These are important organs of absorption. The entire surface of the villi, the glands, and the plane surface of the intestine between these structures is lined with a continuous membrane composed of columnar cells, which separates blood vessels and lymphatics in the intestinal wall from the cavity of the intestine (see Fig. 59). The products of digestion must therefore pass either through these cells or between them to enter the blood or lymph.

The intestine is some twenty or twenty-five feet in length, and the intestinal glands (Fig. 58) constantly secrete intestinal juice upon the contents as they are slowly moved along the tube. Two other juices are added to the intestinal contents almost immediately after their entrance to the upper part of the small intestine. These are the pancreatic juice and the bile, which are secreted, respectively, by the pancreas and the liver. The entrance of the ducts of these glands is shown in Fig. 54. It is not necessary for our present purpose to describe the minute structure of these organs; it is enough for the student to understand that they are glands (p. 29) which pour their secretions through ducts into the intestine very much as the salivary glands pour their secretions into the mouth.

26. The mechanism of secretion of pancreatic juice, bile, and intestinal juice. The mechanism which evokes the secretion of the pancreatic juice has already been described (p. 89). It will be recalled that the lining cells of the intestine immediately beyond the pylorus (duodenum) contain a material which when acted upon by the hydrochloric acid of the chyme is transformed into the hormone secretin. This is absorbed into the blood and chemically excites the pancreas to secrete.

The secretion of bile by the liver is continuous, although it is greater at one time than at another. Circular muscle fibers at the mouth of the bile duct close the opening into the intestine when bile is not needed there; at such times the bile secreted accumulates in the gall bladder. During active digestion the mouth of the bile duct remains open and the bile flows immediately into the intestine.

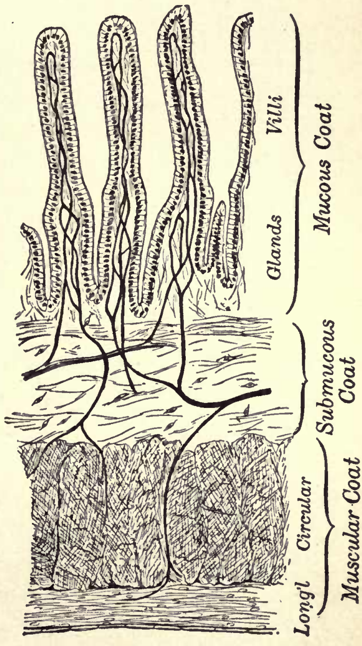


FIG. 58. Longitudinal section of the small intestine

The submucous coat consists of connective tissue and contains the larger blood vessels from which the mucous and muscular coats are supplied with blood

Little is known of the factors determining the secretion of intestinal juice, but it probably is continuously secreted, at least so long as food is in the intestine. Thus each consignment of chyme from the stomach receives its share of pancreatic juice and bile soon after it enters the duodenum, and then subsequently receives continuous additions of intestinal juice as it is passed along the intestinal tube by the action of the muscular coat presently to be described.

27. The pancreatic juice is a strongly alkaline liquid and consequently, when mixed with the acid chyme, neutralizes most, if not all, of the hydrochloric acid of the chyme. Thus it happens that while the food in the stomach is strongly acid, in the intestine it becomes at once more nearly neutral or even alkaline. Since pepsin acts only in an acid medium, the gastric juice now becomes inactive and is soon destroyed by the pancreatic juice, so that it plays no further rôle in protein digestion. This is henceforward carried on by an enzyme of the pancreatic juice, *trypsin*, which acts most vigorously in a neutral or slightly alkaline medium. It forms from the proteins of the food the same general class of peptone-like substances produced by the action of the gastric juice, but carries this cleavage further into smaller peptids and even to some extent to the constituent amino-acids. Trypsin continues the digestion of proteins begun by pepsin. Indeed, in some cases the preliminary action of pepsin is necessary, since trypsin does not act so readily upon the original protein as it does upon the earlier products of peptic digestion; upon these cleavage products, however, its action is most vigorous.

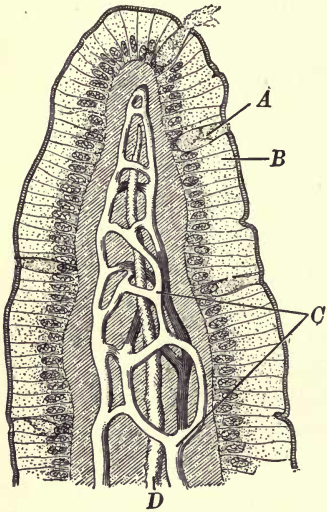


FIG. 59. Longitudinal section of the tip of a villus

Showing the columnar lining cells *B* through which the products of digestion must pass on their way to the blood vessels and lymphatics. The connective tissue between the columnar cells and the vessels is indicated diagrammatically and without showing its structure. *A*, cell which manufactures mucus; *C*, capillaries; *D*, lacteal, or lymphatic

In addition to trypsin the pancreatic juice contains at least two other important enzymes. One of them, *amylopsin*, is practically identical with the ptyalin of the saliva and changes starch into sugar much as happens in salivary digestion. The other enzyme, *lipase*, acts upon fats, changing them into fatty acids and glycerin. We cannot go into the details of the somewhat complicated digestion of fats. The change, like that of proteins into peptones and of starches into sugar, involves the formation of a smaller molecule, either of fatty acids or soaps, or both, and it is probably in these forms that fats are received from the intestine by the villi.

The pancreatic juice thus contains a special enzyme for each of the three great classes of nutrients — proteins, fats, and carbohydrates — and thoroughly completes their digestion after they have undergone the preparatory processes effected by cooking, mastication, and gastric digestion. *Pancreatic juice is by far the most important of the digestive juices in producing the chemical changes of digestion.* In this respect, also, we may say it is of primary importance in the work of intestinal digestion, the other two juices, the bile and the intestinal juice, acting as aids in its work.

28. The bile contains no enzymes of importance in digestion. It is in fact partly an excretion, some of its constituents being waste products which are poured into the intestine only to be ultimately discharged from the rectum. Other constituents of the bile play an important rôle in the digestion and absorption of fats, as is shown by the fact that if bile be prevented from entering the intestine, from forty to sixty per cent of the fat eaten fails of absorption and is discharged with the feces. It is probable that this is because certain soaps formed in pancreatic digestion are not soluble unless bile is present. When these soaps are not dissolved, they are not only themselves not absorbed, but, by being precipitated and adhering to other still undigested food, prevent ready access of enzymes and so greatly retard digestion.

29. The intestinal juice contains two kinds of enzymes, one acting on protein, the other on carbohydrate material. The former class, represented by the single enzyme *erepsin*, has no action on the proteins of the food, but splits peptones and other products of gastric and pancreatic digestion into very small peptids and amino-acids. A similar thing is true of the carbohydrate enzymes — they have no action on starch nor on dextrines (p. 105), but disaccharides (that is, sugars formed by the chemical combination of two simple sugars, as dipeptids are combinations of two amino-acids) are readily split into their component simple sugars. Cane sugar (sucrose) and milk sugar (lactose) are two carbohydrate foods which belong to the disaccharides; a third is maltose, which is the stage in the cleavage of starch preceding the final separation into its component molecules of grape sugar (dextrose). These *inverting enzymes* insure the complete cleavage of the larger carbohydrate molecules into their component sugars, precisely as erepsin insures the complete cleavage of the large protein molecule into its component amino-acids or smaller peptids.

Another most important character of the intestinal juice is its large content of alkaline salts, especially sodium carbonate (soda). Two processes constantly occurring in the intestine produce acid; these are (1) the splitting of the fats into fatty acids and glycerin by lipase and (2) the bacterial decomposition of carbohydrates and (to some extent) of proteins. The sodium carbonate of the intestinal juice, which, it will be remembered, is being secreted along the entire length of the intestine, neutralizes these acids and so maintains the reaction of the contents at an approximately neutral point. This reaction is most favorable for the action of the enzymes present. The combination of sodium carbonate with fatty acids, moreover, forms soaps, which are more readily soluble than the fatty acids. In this way no doubt the products of fat digestion are more promptly absorbed than would otherwise be the case.

30. Action of the muscular coat of the small intestine. The object of the movements of the intestine is not the grinding down of the food into smaller masses, but, in the first place, the agitation of the digesting mixture so that, on

TABULAR SUMMARY OF THE CHEMICAL PROCESSES OF DIGESTION

Foods	Enzymes	Organs secreting Enzymes	Place of Action of Enzymes	Intermediate Cleavage Products	Final (or End) Products of Digestion
Protein foods	Pepsin Trypsin Erepsin	Stomach Pancreas Intestine	Stomach Intestine Intestine	Proteoses Peptones Peptids	Peptids Amino-acids
Starch	Ptyalin Amylopsin	Salivary glands Pancreas	Mouth Cardiac end of stomach Intestine	Dextrines	Maltose
Cane sugar	Inverting enzymes	Intestine	Intestine		Glucose + fructose
Milk sugar	Inverting enzymes	Intestine	Intestine		Glucose + galactose
Maltose	Inverting enzymes	Intestine	Intestine		Glucose
Fat	Lipase	Pancreas	Intestine		Glycerin Fatty acids Soaps

the one hand, good contact is secured between food particles and digestive juices, while, on the other hand, the products of digestion are quickly brought into contact with the villi for absorption; and, in the second place, the slow movement of the food onwards in the intestinal tube. To accomplish these ends there are two kinds of intestinal movements.

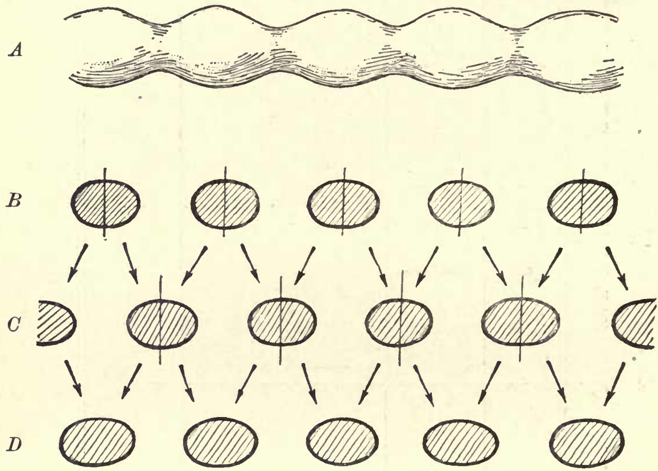


FIG. 60. The divisive, or segmenting, movements of the small intestine

A, surface view of a portion of the intestine, showing six constrictions which divide the contents into five segments, as shown in *B*; as these constrictions pass away, new ones come in between them and divide each segment of the contents into two, the adjoining halves of neighboring segments fusing to make the new segments shown in *C*. Repetition of this process results in the condition shown in *D*

31. Divisive, or segmenting, movements. The food is not distributed continuously along the entire length of the intestine, but is subdivided into a number of separate portions which lie in different loops of the tube. This is partly explained by the intermittent character of the discharge of the chyme from the stomach. The number of these portions varies at different times, but may be as many as twenty or even more. A certain number, sometimes all, of these masses of food will be seen to undergo division into small segments, obviously produced by a series of constrictions of the walls, as shown in Fig. 60. The next moment these are replaced by a second series of constrictions between the first. Each segment is thus divided into two, and the neighboring halves of these segments fuse. The next moment the second series of constrictions is replaced by the first, and this process continues at times for many minutes *with no change in the general position of the food mass.* These divisive, or segmenting, movements occur from twenty to thirty times a minute, and it has been estimated "that a slender string of food may commonly undergo division into small particles more than a thousand times while scarcely changing its position in the intestine."

32. Peristalsis. Every now and then a ring of constriction, instead of being confined to one place, moves onward, pushing the contents of the tube before it for a short distance (two or more inches). A contraction of this kind is called peristaltic. The effect produced is much the same as when the contents of a rubber tube are emptied by squeezing it along between the thumb and finger.

Thus each consignment of chyme delivered from the stomach immediately receives its share of pancreatic juice and of bile, and the final transformation of the digestible foods takes place as the whole is driven from time to time along the intestine by peristaltic contractions, the efficiency of the contact of the food with the digestive juices, as well as its exposure to the absorbing surfaces, being greatly enhanced by the agitation produced by the movements of constrictive division carried out by the circular muscles between periods of peristaltic activity. *The efficiency of digestion and absorption depends as much on the movements carried out by the muscular coat as on the chemical processes effected by enzymes and other constituents of the digestive juices. Digestion is always a coöperation of chemical and mechanical work.*

So far as is known, these movements are aroused by the distention of the intestine with food and possibly by chemical stimulation of the muscular coat by substances formed within the tube. The presence of solid indigestible material also favors the movements.

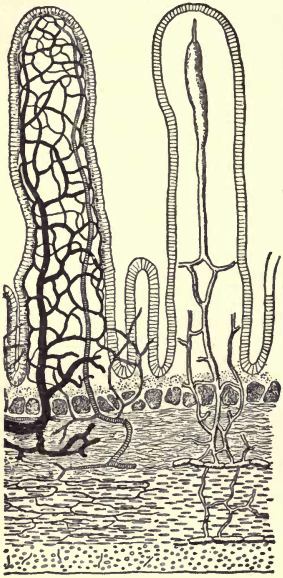


FIG. 61. The intestinal structures concerned in absorption

In one villus is shown the close network of blood vessels immediately under the lining membrane; in the other villus, the central lymphatic, or lacteal. Observe that the products of digestion must first be exposed to absorption by the blood vessels before they can enter the lacteal

33. Absorption is the name given to the passage of digested food materials from the cavity of the intestine into the blood. The word itself perhaps suggests that the products of digestion are received into the blood without change, as a sponge might absorb a mixture of peptids, amino-acids, sugar, fatty acids, soaps, and inorganic salts. Such, however, is by no means the case, and the actual physical and chemical processes of absorption are complicated — far too complicated to be discussed here. Suffice it to say that the intestine is not lined by a dead membrane but by living cells, and through these guardian cells the products of digestion must pass to enter the blood (see Fig. 59). In their passage through these cells some of the digestive products are acted upon chemically so that they enter the blood in forms more available to the tissues of the body. The object of the whole process of alimentation, digestion, and absorption would seem to be that of supplying food to the muscle fiber, the gland cell, the nerve cell, etc., through the blood as an internal medium or middleman, in that form which is best fitted for the use of the tissues.

34. Digestion in the large intestine. The large intestine contains no villi, and its glands secrete an intestinal juice characterized by a large content of mucin (p. 44).

In the small intestine the amount of water added by secretion balances that absorbed, so that the consistency of the contents undergoes but little change from the stomach to the beginning of the large intestine. This consistency, it will be

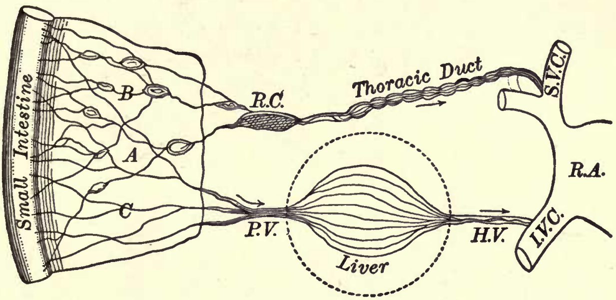


FIG. 62. The paths by which the products of digestion enter the general circulation

Those which are absorbed by the blood vessels (C) of the intestine pass by the portal vein ($P. V.$) to the liver before they can enter the right auricle ($R.A.$) through the hepatic vein ($H. V.$) and the inferior vena cava ($I. V.C.$). Those products which are absorbed by the lacteals pass directly to the superior vena cava ($S. V.C.$) through the thoracic duct

remembered, was (approximately) that of moderately thick pea soup. During the passage through the small intestine the digested portions of the food are being removed by absorption, while the indigestible elements are left behind. Among the indigestible elements of food are certain connective tissues of the animal foods, but especially the cellulose (p. 97), which forms the cell wall of plant tissues. The large intestine receives from the small this indigestible material, together with a certain variable but usually comparatively small proportion of the proteins, fats, and carbohydrates which have thus far escaped digestion; in addition there are certain constituents of the digestive juices which are not absorbed and some (for example, certain constituents of the bile) which are distinctly excretory products.

Special provision seems to be made to insure the approximately complete digestion and absorption of proteins, carbohydrates, and fats before the food enters the large intestine. The opening from the small into the large intestine is guarded by a circular muscle, the *ileocolic sphincter*, which ordinarily prevents the passage of food out of the small intestine much as the passage of food from the stomach is regulated at the pylorus (p. 113). In this manner considerable accumulations of material may occur at the end of the small intestine and remain there for two hours or more while the combined action of enzymes and segmenting movements completes the digestion and absorption of the nutrients. Recent work indicates that this material is discharged periodically into the large intestine by a relaxation of the ileocolic sphincter and a vigorous peristalsis in the terminal portion of the small intestine. It would also seem that this discharge is especially apt to occur when food is taken into the stomach, as if there is a reflex to this discharging mechanism. Obviously the end attained is the more complete digestion of the food in the small intestine.

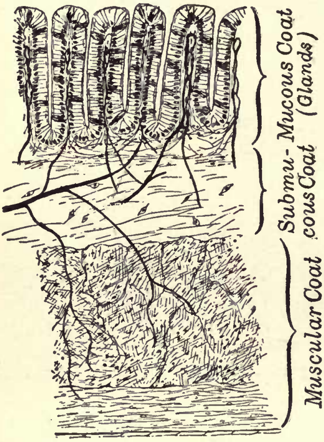


Fig. 63. Longitudinal section of the large intestine

Note the absence of villi

Reference to Fig. 154 will show that the large intestine consists of four parts, the ascending, transverse, and descending colons and the rectum, there being an S-like bend

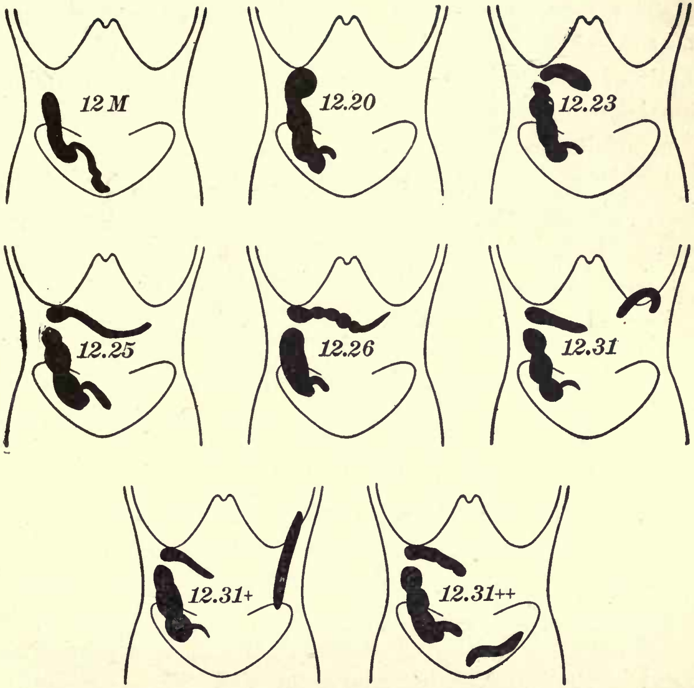


FIG. 64. Action of the muscular coat of the large intestine, as shown by the X-rays. After Hertz

The lower border of the ribs and the upper border of the pelvis are sketched. Black shadows are the food masses in the lower small and the large intestine. Breakfast about 7 A.M. For some time before noon the food shadows showed no change (12 M). Shortly after 12 luncheon was taken. At 12.20 the food accumulated in the lower small intestine had been discharged into the ascending colon, which it distends. At 12.23 the distal end of this food mass was constricted off and later (12.25) passed along the transverse colon, where divisive movements take place (12.26); but at 12.31 the distal part of this mass is separated and rapidly passed through the descending colon (12.31 +) to the sigmoid flexure (12.31 + +)

(*sigmoid flexure*) between the descending colon and the rectum. The ascending colon is always filled, while the rest of the tube may be empty. It is chiefly in this first part of the tube that the abstraction of water occurs. When, as the result of the discharge of new material from the small intestine into the large, the ascending colon becomes distended, some of its contents are pushed into the transverse colon, and this material is rather rapidly passed by peristalsis through the descending colon, in the lower part of which it accumulates, being prevented from entering the rectum by the sigmoid flexure. Finally, with sufficient accumulation of this more solid material at the sigmoid flexure, stronger peristaltic contractions move the mass on into the rectum, which thereby becomes distended, and this gives the desire to empty the bowels. From this it will be seen why the bowels are more readily emptied after meals. It is also highly advisable to empty the bowels when this desire comes on, since otherwise the distending stimulus loses its effectiveness and the continued abstraction of water hardens the feces.

35. Microbic life in the intestine. Occurring simultaneously with the chemical changes produced by the digestive juices are others produced by microbes (Part II), which are always found in the intestine in large quantities. The acidity of the gastric juice keeps down the numbers of these germs in the stomach and, under healthy conditions, greatly limits their activity in that organ. We have seen, however, that some portions of the contents of the stomach are not acid in reaction during certain periods of digestion, and it not infrequently happens for this reason that unhealthy living and, especially, improper feeding may result in serious gastric indigestion with excessive bacterial decomposition of the food. The production of gas, leading to flatulence or belching, is one of the most familiar results of such bacterial action.

In the intestine the less strongly acid (or even neutral or slightly alkaline) reaction is much more favorable to bacterial life and growth, and we accordingly find that the number of microbes is much greater in the small and large intestines. It is not the microbe itself, however, which is of importance to the organism as a whole, but the substances which it produces from the foods. Most of these substances are either harmless themselves or else are readily changed into harmless substances either before or soon after entering the blood; others are poisons, but are normally present in such minute quantities as to be entirely negligible; more rarely they are produced in large quantities and may cause various ill effects either locally or upon the body as a whole.

The production of undue quantities of such harmful substances, most of which are derived from proteins, is chiefly dependent upon the food supply of the bacteria. This is normally kept low by the speedy and efficient removal of the peptones. Native[1] proteins are acted on comparatively slowly by bacteria and, in any case, must first be changed into peptones or simpler peptids before they can be further broken down into harmful bodies. If, however, the processes of absorption quickly and efficiently remove the digestive products, subsequent harmful decomposition of the food is prevented, for there are normally no bacteria in the blood. It is therefore of great importance to maintain the efficiency of absorption. This can be done in general only by leading a normal life — by taking sufficient muscular exercise, by proper habits of sleep and rest, by proper feeding, and so on. The hygienic conduct of life tends to maintain all functions of the body in proper working condition, those of the digestive organs included; and nothing else can be depended on, in the long run, to do this. To this subject we shall return in the chapters on hygiene, when dealing directly with the personal conduct of life.

[1] A "native" protein is a protein as it occurs in nature before being changed by digestion or other chemical action. The proteins in food are largely native proteins or else, what amounts to the same thing, as far as the action of bacteria is concerned, native proteins coagulated by heat.

The chief seat of the putrefactive decomposition of proteins is in the large intestine, where conditions are favorable for the activity of the special bacteria responsible for this food change. The reader will recall the provisions for completing the digestion of proteins and carbohydrates in the small intestine, and these certainly play a very important rôle in limiting harmful microbic action in the large intestine. It often happens, especially in middle life, that the quantity of food eaten, and of protein food in particular, must be considerably diminished to insure complete digestion of these nutrients in the small intestine and thus deprive the putrefactive bacteria of the large intestine of the material out of which to make deleterious substances.

We have thus far been dealing only with those microbes commonly found in the intestine. At times foreign microbes find entrance, some of which cause such diseases as typhoid fever, dysentery, cholera, etc. The action of these occasional intruders will be more fully dealt with in Part II.

36. The elimination of intestinal waste. Those who are "blessed with a good digestion" sometimes find it hard to realize that the preparation of food for absorption through the delicate membranes lining the alimentary canal is a difficult and complex process, requiring much delicate physical and physiological apparatus and involving various and important chemical reactions. Even when they realize this, they rarely appreciate the indispensable coöperation and fine adjustment of the several parts and processes concerned. It is just here, however, that a clear understanding is important, for without this it is not easy to see how disorders of digestion arise.

Let us then remember that the efficient handling of the food in the stomach is aided by the preparatory crushing it receives in the process of mastication; that in the stomach an adequate and efficient secretion of gastric juice must take place, and that this begins as the result of nervous events connected with our enjoyment of the food when eaten; that the continued secretion of gastric juice is secured, in turn, by stimulation of the mucous membrane of the stomach by the peptones which the psychic secretion has formed from the proteins of the food; and, finally, that the chemical action of the gastric juice is aided by the peculiar contractions of the muscular coat of the stomach. All these agencies *working together* deliver the food to the intestine in a finely divided state, well adapted and indeed absolutely necessary to secure the proper contact of the food with the pancreatic juice, the bile, and the intestinal juice.

The flow of pancreatic juice, in turn, is partly the result of the action of the hydrochloric acid of the chyme on the walls of the intestine, while the efficiency of the action of the pancreatic enzymes depends upon the simultaneous action of the bile and the intestinal juice; lastly, the chemical action of these juices, as well as the final act of absorption, requires the coöperation of the muscular coat. Healthy conditions with respect to bacterial action similarly depend upon all else occurring as it should. *Digestion, in short, is a chain of events*, each depending upon those which have gone before and, to a large extent, upon those which are taking place at the same time.

Keeping these facts in mind, it is easy to appreciate the possibility of diarrhea or constipation, the latter consisting in the retention of wastes, the poisonous constituents of which may be absorbed into the body and cause discomfort, headaches, and malaise. When all the digestive processes work together properly there should be a perfectly natural and regular evacuation of the bowels. The frequency of such evacuation varies somewhat and is largely a matter of habit; with some people it is twice a day, with others once every other day, *but with the vast majority it is normally once every day and at about the same time.* Where this is not the case there is reason to believe that some part of the work of digestion is not being properly performed. The trouble is not ordinarily in the mechanism governing the actual discharge of the feces from the rectum, but in a derangement somewhere else; it may be entirely the fault of the mechanism of peristalsis, or it may be due to imperfect secretion. In all cases it means that *something is wrong*, and the remedy should be sought not in drugs or pills but in search for and *removal of the cause.* A moment's consideration will show the reasonableness of this position. If a watch loses time because it needs cleaning, we do not seek a remedy in drugs, but in its cleaning, better adjustment, and good care; and the remedy for diarrhea or constipation should in all cases be sought for in the better conduct of life. Is enough muscular exercise being taken? Is the diet properly chosen? Are we drinking enough water? Especially, is the food of sufficient bulk and does it contain enough laxative material (such as fruit)? Above all, are we getting enough sleep? Are we overworking, or do we work too long at a time without resting? Is our clothing warm enough, or are we overclad? Such are the questions which should be seriously asked. The student of personal hygiene cannot lay to heart too seriously the truth that the man who goes from day to day, from week to week, from year to year, neglecting the warnings of diarrhea or constipation, only reaps the harvest of his folly when in later years he suffers loss of health and at times bodily discomfort; and it is nothing short of impiety to marvel under such circumstances at the "mysterious" ways of a Providence which so "afflicts" his creatures. It is no exaggeration to say that the regular discharge of the wastes is quite as important as the regular feeding of the body and that no less pains should be taken to form good habits in the one case than in the other. Many of the headaches, many of the bad feelings, and many of the bad tempers of the world are due to neglect of this simple fact. No city, however well fed or beautiful, the drains of which are choked with filth, can long remain either wholesome or attractive — and the human body is essentially a city teeming with living cells.

CHAPTER IX

THE CIRCULATION OF THE BLOOD

A. Blood and Lymph

1. The blood as a common carrier. In previous chapters some of the more general features of the circulation have already been touched upon. In studying the parts of the body the student has become somewhat acquainted with the heart, the arteries, and the veins; in considering the typical structure of the organs (Chap. III) he has seen how the arteries are connected with the veins by a system of communicating tubes, the capillaries, through the thin walls of which interchange takes place between the lymph and the blood; and in studying the interdependence and coöperation of the cells and organs (Chap. VI) he has learned how the blood leaving each organ returns to the heart, there to be mixed with that coming from all other organs and thence pumped first to the lungs and then to the rest of the body. The need of a circulation is obvious, for the food received from the alimentary canal and the oxygen received from the lungs must somehow be carried to the muscle fibers, the nerve cells, the gland cells; the cellular wastes must be taken away to the organs of excretion; and the internal secretions of the body must be transported from the organs in which they are made to those in which they are to be used. In other words, it is a necessary corollary to the fact that no cell or organ "liveth unto itself" that there should be some common carrier of matter and of energy from one organ to another. Such a common carrier is the blood. The analogy of the blood system of the body with the railway system of a country is instructive. As different persons and different communities in any country make different products and have different needs, it becomes more and more necessary that the means of communication between them be extensive and efficient. Hence the remarkable growth of the railroads, or "common carriers," of any country in which industrial development produces increasing division of labor.

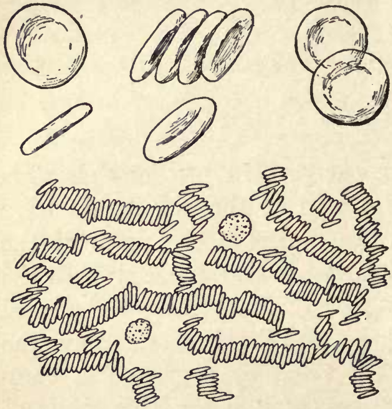


FIG. 65. Structure of a drop of blood as seen under the microscope

Above are shown nine red corpuscles highly magnified; below, less highly magnified, the appearance of the blood soon after being drawn. Two white corpuscles are shown, and the red corpuscles stick together, forming "rouleaux." Size of red corpuscle, 7.7 μ wide, 2–4 μ thick. Diameter of white corpuscle, 5–10 μ. Number of red corpuscles, 4,500,000–5,000,000 per cubic millimeter; number of white corpuscles, 4500–13,000 per cubic millimeter, according to the state of digestion, etc. Surface area of all the red corpuscles of the blood, 3000 square meters (30,000 square feet or approximately four times the size of a baseball diamond). (1 μ, or *micron* = 0.001 millimeter)

The blood, which is thus the common carrier first between the various organs and second between each organ and the outer environment, is the net product of the united work of all the organs: from the alimentary canal it receives water and the products of digestion; from the lungs it receives oxygen; each organ contributes its share of waste products or of internal secretion, while some influence the composition of the blood by removing from it certain things that it contains.

2. The microscopic structure of the blood. Examined under the microscope the blood is seen to consist of a liquid portion, the *plasma*, crowded with small solid bodies, the corpuscles. These are of two kinds: the *red corpuscles* — biconcave disks containing a pigment, *hemoglobin*, which gives the red color to the blood; and the *white corpuscles*, which are colorless, nucleated cells.

Important data on the number, size, and surface area of the corpuscles will be found in connection with Fig. 65.

3. The white blood corpuscles. The white blood corpuscles really comprise several different kinds of cells, having different functions, the study and explanation of which belong to advanced rather than to elementary physiology. It is enough for our purpose to state that these cells are not confined to the blood, but work their way out of the blood vessels between the cells of the capillary walls and are often found in the lymph spaces of the tissues as *wandering cells.* The latter term refers to their movement from place to place. The cytoplasm of the white corpuscle is a thick, viscous fluid without constant or definite form. In locomotion the cytoplasm flows slowly from some part of the surface in the direction of motion, forming what is known as a *pseudopodium* (from the Greek, meaning a false foot), as shown in Fig. 66; the rest of the body of the corpuscle then flows into the pseudopodium. By the continuation of this process the white corpuscles make their way through the spaces of the connective tissue. Locomotion by means of pseudopodia is frequently spoken of as *amœboid*, from the amœba, a unicellular animal which moves in the same manner. (See Chapter XXIII for examples of the functions of white blood corpuscles.)

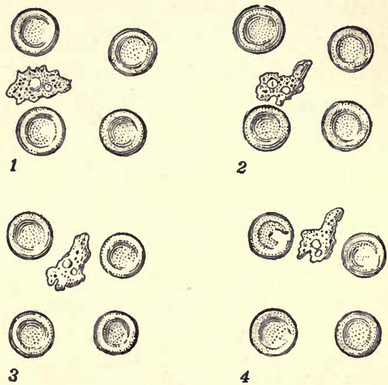


Fig. 66. Amœboid movement of a white corpuscle

Showing four consecutive positions among a group of red corpuscles

4. The red blood corpuscles. The red corpuscles are pigmented, biconcave disks with no nucleus; they are normally confined to the blood vessels and are carried around passively in the blood current without active movements of their own. The main function of these corpuscles is to carry oxygen from the lungs to the tissues, a function which will be further studied in connection with respiration. They contain a pigment, *hemoglobin*, which gives to the blood its red color and carries the oxygen.

5. The blood plasma is an exceedingly complex fluid whose general composition is represented as follows: water, 90 parts; solids, 10 parts (proteins, 8 parts; inorganic salts, 1 part; extractives, 1 part).

Under the extractives are included a very large number of substances which, though present in small quantities, are interesting to the physiologist because they are largely products of the chemical activities of the body and as such give information about the nature of the chemical changes occurring in the organs.

Finally, it should be remembered that the cells of the body generally are bathed with lymph, not with blood; in other words, that the lymph and not the blood is the immediate environment of the cells. Lymph is sometimes described as blood minus its red corpuscles; but this statement, though convenient, is not strictly correct, since the amount of waste products in lymph must be greater than in blood, while the amount of food material must be less (see Chap. IV). Much as the blood is a product of the united chemical activity of all the organs of the body, so the lymph of each organ is derived from the cells of that organ and from the blood flowing through it. Lymph thus has a double origin and of course shows very considerable differences of composition in different organs.

B. Mechanics of the Circulation of the Blood and of the Flow of Lymph

The greatest discovery ever made in physiology was that of the circulation of the blood. As late as the settlement of the earliest English colonies in America it was thought that the blood moved back and forth in the blood vessels, as the waters in the sea ebb and flow; but of any *circulation*, in the sense of a steady stream returning to its source, there was no idea; and it was not until 1621 that William Harvey, an English physician, proved beyond the shadow of a doubt that the blood in the body of all the higher animals flows like a stream always in one direction, ultimately returning to its source.

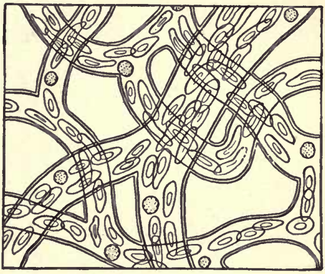


Fig. 67. The circulation of the blood as seen in the small arteries and capillaries of the web of a frog's foot

Tests made upon various animals have shown that this circulation is accomplished in the surprisingly short time of from twenty to thirty seconds; which means that the whole mass of the blood (in man about twelve pints) passes between three and four thousand times a day through the various organs of the body, bringing to them their food, carrying away their wastes, and in general helping to maintain normal conditions. By what hydraulic machinery is this marvelous work done?

6. The motive power of the circulation as a whole; the beat of the heart. Whenever a mass of liquid is kept in motion we naturally look first for the motive power. In answering the question, What makes the blood circulate? we shall find that while there are several causes, one of these, namely the beat of the heart, is vastly more important than all the others combined. This fact is now so familiar that it is hard to realize that we owe to Harvey not only the discovery of the circulation but also the discovery of the meaning of the heart beat. Before his time, to be sure, the living heart had been seen at work, alternately shrinking in size and then swelling, the shrinking being called *systole* and the swelling *diastole*; but these changes in size were regarded as the results of the contraction and expansion of certain "vital spirits" which the arterial blood was then supposed to contain, and not as muscular contractions and relaxations. Harvey showed that *the heart is a powerful muscle* and that its systole is a muscular contraction; that during systole it becomes hard, just as the biceps muscle does when it shortens, and during diastole soft and flabby; he also proved that with each systole the heart drives or spouts blood into the large arteries (the aorta and the pulmonary artery), and that this blood is prevented from flowing back into the heart during diastole by membranous valves at the very beginning of the large arteries in question.

7. The heart a muscular force pump. The beat of the heart, even to its most minute detail, is one of the most important as well as one of the most interesting subjects in physiology; everything in the body hangs on its proper efficiency and regulation, and it cannot be too thoroughly studied. For our present purposes it will suffice to describe the heart as composed essentially of a pair of muscular force pumps. Dissection shows that it is divided into right and left halves (see Fig. 70), completely separated from each other, and that each half consists of two chambers — an auricle and a ventricle. The auricles, into which the great veins open, have thin muscular walls and are comparatively small in size; the ventricles, on the other hand, from which the great arteries arise, have thick muscular walls, especially the left ventricle. The ventricles, indeed, constitute the principal part of the force pump; the auricles merely facilitate the work of the ventricles and for purposes of elementary study may be mostly neglected. The student should, if possible, examine for himself and actually handle the auricles, ventricles, and great blood vessels of a sheep's heart, which in size and structure sufficiently resembles the human heart. Figs. 15 and 162 should also be consulted.

8. The mechanics of the heart beat. All force pumps consist of two indispensable parts — some device for pressing upon a liquid within a chamber, and valves at the openings of the chamber so arranged as to allow the passage of the liquid in one direction only. Each ventricle of the heart is really such a pump and is provided with two sets of valves — one set at the inlet, between the auricles and the ventricles, and the other at the arterial outlet. These valves permit blood to pass only from the great veins through the auricles and on through the ventricles to the great arteries. The contraction of the muscular wall of the ventricles produces pressure on the blood within their cavities; this pressure quickly and easily closes the auriculo-ventricular valves and finally forces open the shut valves at the openings of the great arteries. In this way the right ventricle drives venous blood into the pulmonary artery, and the left ventricle arterial blood into the aorta. With the relaxation of the ventricles (diastole) pressure falls within their cavities, and were it not for the valves at the mouths of the aorta and the pulmonary artery, blood would regurgitate, or flow back, into the heart; but this "slip" (as it is

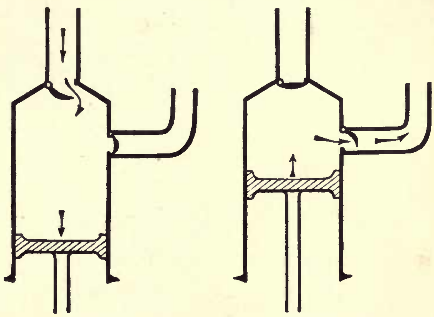


FIG. 68. Diagram of the action of a force pump

called in hydraulics) the valves prevent, and the ventricles again fill through the only open channel, that is, the one leading from the great veins and the auricles. Thus by contractions rhythmically repeated the heart continues to spout or deliver blood from the two sets of great veins into the two sets of great arteries. It is plainly a double force pump or, better, a pair of force pumps lying and working side by side.

9. The arterial and the venous reservoirs. To understand the exact nature and result of the work of the heart we must now consider the relation of this living pump to the pipe system (arteries, capillaries, and veins) with which it is connected. The student should first trace the general course of the circulation in the simple diagrammatic representation given in Fig. 70. This shows that the blood which enters the aorta from the left ventricle must return to the right side of the heart and pass through the lungs before it can again reach the aorta. As the physical principles of the circulation are the same for the systemic and the pulmonary vessels, we shall confine our attention to the former.

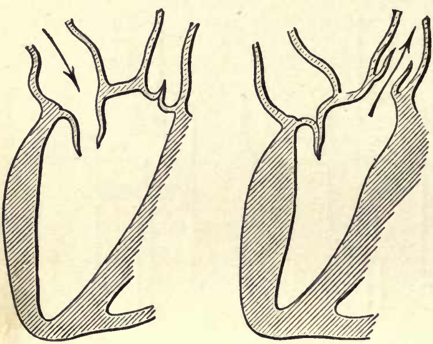


FIG. 69. The force-pump action of a ventricle of the heart

On the left is shown the condition during diastole; on the right, during systole

In the first place, we may observe that the heart pumps the blood into what is practically a large reservoir (the larger arteries) and that the blood flows from this reservoir to a second reservoir (the larger veins) *by various routes*; for the vessels of the different organs represent many alternative courses which the blood may take in flowing from the arterial to the venous reservoir. The blood stream, indeed, may be compared with a stream supplying water power to a series of mills in a manufacturing town. The larger arteries from the main source of pressure (the heart) correspond to the headrace from above the dam, while the larger veins correspond to the tailrace. The water flows from the one into the other only through the smaller sluices, or penstocks, which supply the mills. So in the vascular system a part of the blood pumped into the arterial reservoir, or aorta, finds its way into the venous reservoir by way of the skin, another part by way of the digestive organs, another by way of the brain, still another by way of the kidneys, and so on; but the flow in every case is essentially the same, namely from a reservoir of high pressure to one of lower pressure.

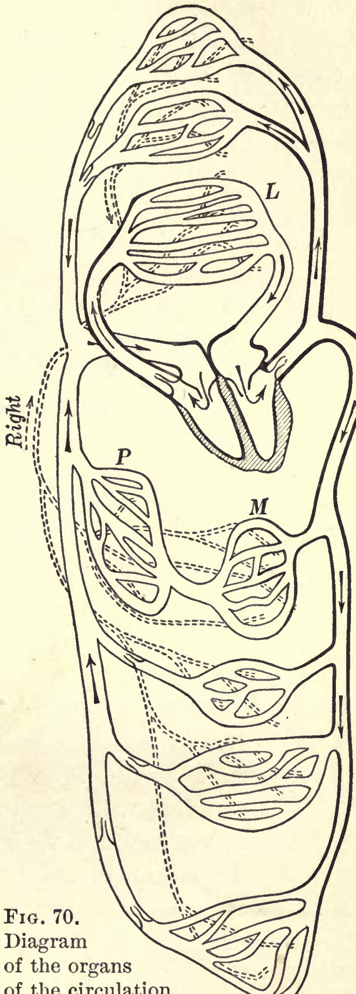


FIG. 70. Diagram of the organs of the circulation

L, pulmonary circulation; *M*, circulation through the organs suspended by the mesentery, the blood being carried to the liver *P* before it returns to the heart. The circulation through other organs, such as brain, muscles, skin, and kidneys, is indicated. Lymphatics are represented by dotted lines

10. The driving force for the flow of blood from the aorta; pressure in arteries and veins. The hydraulic conditions in the aorta may be illustrated by means of the following simple piece of apparatus: To an ordinary rubber syringe attach a piece of elastic rubber tubing, the other end of which is closed by a detachable nozzle. If now the nozzle be removed and water pumped into the tube, it will be found that the flow from the open end consists of squirts or spouts and continues only during the stroke of the pump; if, however, we attach the nozzle and again pump water into the tube, the resistance caused by the small orifice of the nozzle prevents the water from flowing out of the tube as fast as the syringe pumps it in. *The tubing becomes distended with water.* Since, however, the tube is elastic,[1] and so tends to return to its original size, it forces the liquid out through the nozzle even between the strokes of the pump. The immediate cause of the steady flow from the nozzle is therefore the elastic squeeze of the rubber tube. The intermittent stroke of the pump produces distention of the tube, and the elasticity of the distended tube constantly forces the water out of the nozzle.

Closely similar conditions obtain in the arterial reservoir. Here the outlet is also through very small tubes, the small arteries, whose bore is not greater than $\frac{1}{50}$ or $\frac{1}{100}$ of an inch; which fact introduces the same condition as does the nozzle of our apparatus, that is, a *resistance* to the outward flow of the blood. Consequently the blood cannot flow out of the aorta as rapidly as it is driven in, and the extensible and elastic walls are necessarily stretched. The immediate effect

[1] An elastic body is one *which returns to its original shape* when it has been stretched, compressed, or otherwise deformed. Elasticity must not be confounded with "extensibility," or the property of allowing stretching. Thus when we "pull" taffy we deal with a body which is very extensible but which is practically inelastic. A body, indeed, may be extensible only with difficulty, but possess a very high degree of elasticity; ivory is a good example of this kind.

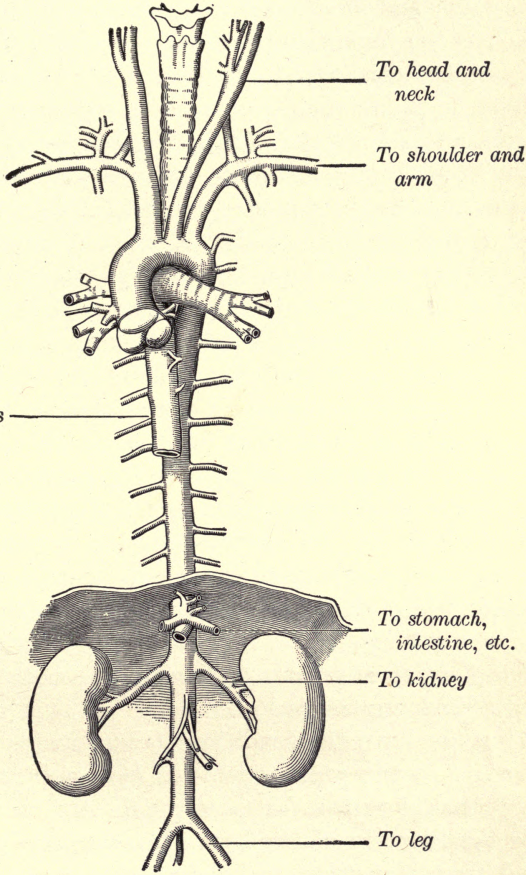


FIG. 71. The aorta and its main branches

At the beginning are shown the three pocket valves which prevent regurgitation of blood during diastole of the heart beat is to keep the arterial reservoir overfilled or distended, so that the *elastic reaction* of its walls is brought into play; and it is this elastic reaction of the arterial walls which is the immediate cause of the steady outflow through the small arteries and capillaries.

The force of compression, or *pressure*, exerted by the elastic arterial walls is primarily exerted upon the blood within them; and the more the arteries are distended the greater will be the pressure exerted on the blood. A liquid thus under pressure tends to find an outlet; should any part of the arterial wall be weak, as sometimes happens in diseased conditions, it is bulged outward; and, for the same reason, a flow of blood will take place through such outlets as are presented by the smaller arteries and capillaries. Moreover, the greater the pressure of the blood in the arteries, the more rapid will be the flow into the capillaries. Hence it is customary to use the *arterial blood pressure* as a measure of the force of elasticity exerted by the distended arterial wall.

The veins, on the other hand, are less elastic than the arteries; they are, indeed, more like mere conducting tubes through which the blood can flow back to the heart. They are not overfilled (since, for one reason, there is no resistance to the flow of blood out of them into the heart) and hence *venous blood pressure* is low.

Thus we have the conditions favorable for the flow from the aorta to the great veins — a *high* pressure in the arterial reservoir and a *low* pressure in the venous reservoir. It is the function of the heart, by continually pumping the blood from the veins into the arteries, to keep the arterial reservoir distended, thus maintaining *a difference of pressure in the two reservoirs. It is this difference of pressure which drives the blood through the organs.*

11. The distribution of the blood among the organs. Some organs require more blood than others, and the same organ often requires more blood at one time than at another. Thus muscles and glands, the seat of very active chemical changes, require more blood than a tendon; and a gland requires more blood during the process of secretion than during rest. How is the supply of blood to the organs regulated to meet their varying needs? In the first place, some organs are more vascular than others; those requiring a larger supply of blood receive a greater number of arteries from the arterial reservoir and have a closer network of capillaries. But in addition to this, these smaller arteries contain circular muscle fibers whose contraction diminishes the bore of the tube. When an organ needs more blood the muscle fibers of its small arteries relax, thus permitting the arterial tubes to widen or dilate — just as when we want the water to flow faster from a faucet, we widen the outlet from the pipe by turning the spigot a little further. When less blood is needed the small arteries are caused to constrict, just as a spigot may be partially turned off (see sects. 25–27). In this way the flow of blood to any organ is regulated to meet the varying needs of the organ in question.[1]

12. Secondary aids to the circulation. In the preceding discussion we have seen that the cause of the flow of blood through the organs is the difference of pressure in the two reservoirs. We have further seen that this difference of pressure is maintained by the heart beat in pumping blood from the venous into the arterial reservoir. A moment's consideration will show that anything which hastens the flow of blood from the veins into the heart and so lowers pressure within the veins would similarly aid the circulation,

[1] In order that the student may become more familiar with these fundamental hydraulic principles of the circulation, such questions as the following should be answered: (1) What are the two principal factors whose variations change the amount of arterial pressure? Illustrate by an example or model. (2) How would the dilation of all the arteries of the intestine affect the general arterial pressure? (3) What would be the effect upon the amount of blood flowing through the skin under this condition? (4) How would dilation of the arteries of the skin affect the blood flow through the brain?

since, with the same arterial pressure, more blood will flow into an empty vein than into one which is partially filled.

1. *The breathing movements.* There are two factors which thus tend to empty the veins. The first is the *suction exerted on the blood within the veins by breathing movements.* The exact mechanism by which this is accomplished must be left for consideration in the chapter on respiration. Suffice it to say here that just as the enlargement of the thorax, when we take in a breath, sucks air into the lungs, so it also sucks blood from the large veins outside the thorax into those which lie within it; because of the thickness of the walls of the arteries the same effect occurs to only a very slight extent in the arterial reservoir. During expiration, on the other hand, the reduction in size of the thorax forces air out of the lungs, and we might expect that it would similarly force blood from the veins within the thorax into those without. And this it certainly would do if the veins were not provided with valves which allow the blood to flow only toward the heart. In general, therefore, both inspiration and expiration aid the circulation, the former by sucking blood into the thoracic veins and so emptying those outside, the latter by making this

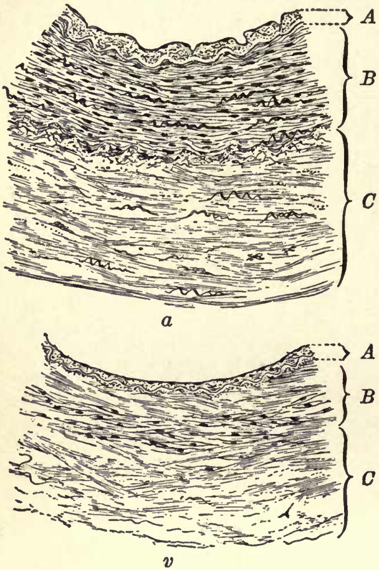


FIG. 72. Cross sections of portions of the wall of a smaller artery (a) and a smaller vein (v)

A, internal coat; *B*, middle coat, with muscle fibers; *C*, outer coat of connective tissue. The contraction of the circularly disposed muscle fibers narrows the bore of the tube blood in the intrathoracic veins flow on more rapidly to the heart, whence it is pumped into the arteries. In a word, deep breathing greatly promotes a good circulation.

2. *Intermittent compression of the veins.* The other secondary factor of the circulation is *intermittent compression of the veins*, and in ordinary life this is brought about in two ways: (1) Whenever a muscle contracts it thickens and hardens; the veins and capillaries which are between the fibers and fiber bundles, or in the connective tissue between two contracting muscles, will thus have the blood squeezed out of them into the large veins; when the muscle relaxes, the empty veins and capillaries will readily fill from the arteries, since the valves of the veins will prevent any backward flow of the blood from the larger veins. Alternate contractions and relaxations of muscles therefore aid the flow of blood through this so-called "pumping" action on the veins. (2) A similar pumping action on the veins is exerted by alternate flexions (bendings) and extensions at any joint. In general, flexions force the blood out of the veins, while extensions allow them to fill. When we remember how largely most of our usual muscular actions consist of alternate flexions and extensions of joints and alternate contractions and relaxations of muscles (for example, in walking and running), we can at once appreciate how greatly muscular activities must aid the circulation. When to the effect of these we add the suction action of the deepened breathing movements, the effect upon the circulation becomes very great.

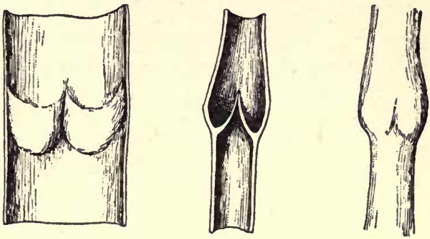


FIG. 73. The pocket valves in the veins

On the right is shown the external appearance of the vein at the valves when the latter are closed; on the left, a vein slit lengthwise and opened; in the middle, a longitudinal section of a vein

13. Massage. The action of massage is only another illustration of the same principle. By rubbing the legs and arms in the direction of the heart, the blood contained in their veins is forced onward and the circulation aided, precisely as when a muscle contracts or one member of a limb is flexed upon another.

14. The lymphatics. Important as are the suction action of the breathing movements and the pumping action of contracting muscles as aids to the circulation of the blood, they are even more important as causes of the flow of lymph along the greater lymphatic trunks toward the heart. Reference to the general method of origin of lymphatics, as described in Chapter III, will show that the lymph in the lymph spaces, unlike the blood in the capillaries, has not behind it a high-pressure reservoir; there is no such *force from behind* to send it onward, since the lymphatics arise blindly in the tissues. What, then, makes the lymph flow along the lymphatics toward the heart?

The lymphatics resemble the veins in structure, having thin walls and pocket valves; like the veins, most of them originate in extrathoracic organs and join or combine to form larger trunks as they proceed toward the thorax. All of them finally unite in two large lymphatics within the thoracic cavity, and these open into the great veins near the heart. (Figs. 30 and 70 should be consulted in this connection.) It is at once clear that the breathing movements must exert on the lymph within these thin-walled vessels exactly the same suction action as they exert on the blood in the veins, and anything which increases this suction action, such as the deepened breathing movements during muscular activity, must necessarily increase the flow of lymph from every organ of the body. On the other hand, a pumping action on the lymph in the organs results from all rhythmic movements of parts of the body with reference to one another, since each change of position carries with it some change of external pressure on lymphatics. Familiar examples are the movements of arms and legs in locomotion, of the diaphragm in breathing, and of the lungs in respiration.

It has also been supposed that a third cause of the lymph flow is the passage of waves of constriction (peristalsis, cf. p. 125) over the larger lymphatics. This, however, probably plays only a minor part.

Finally, in the formation of lymph from the blood, more water generally passes from the capillaries to the lymph spaces than from the lymph spaces into the capillaries. Under these circumstances, at least at certain times, the lymph spaces become distended and a certain low pressure obtains in them. This we may speak of as the "active force" of lymph formation, and it constitutes a fourth factor in causing the lymph flow.

We have already pointed out the importance of the lymph flow in maintaining the lymph currents about the living cells; we are now able to appreciate the importance of those agents which secure this flow. As enumerated above, they are four in number: (1) suction action of the breathing movements; (2) pumping action of muscular or passive movements; (3) active force of lymph formation; (4) peristaltic contractions of the large lymphatics.

Of these the fourth is at least doubtful and in no case of great importance; the other three may therefore be regarded as the chief causes of the lymph flow, and of these the first and second are brought into most effective action by muscular activity; this deepens the breathing movements and so increases their suction action on the lymph, while the movements of the body exert on the lymphatics a pumping action which is largely lacking during complete inactivity. The great practical importance of this aspect of the subject will be discussed beyond in those chapters which deal with the hygiene of muscular activity (Part II).

C. THE ADJUSTMENT OF THE CIRCULATION TO THE NEEDS OF EVERYDAY LIFE

The total quantity of blood in the body (ten to fourteen pints) is not enough to furnish a working supply to all organs at the same time; and since, in general, whenever an organ works it receives more blood, and when it is at rest it receives less, our daily life with its changes of activity among the organs makes necessary frequent adjustments of the circulation to the needs of the organs at various times.

Some of these adjustments are matters of familiar experience. The increased flow of blood to the skin on a warm day makes the veins stand out and the face red, and we are conscious of the more rapid heart beat during muscular activity, even in an act so simple as running upstairs. Other adjustments are not so evident, but betray themselves by their results, as happens after a hearty meal when the demand of the digestive organs for blood lessens the supply to the brain and we feel disinclined to hard mental work. We may begin our study of these adjustments by learning what occurs in the circulation during some of the more common activities and events of daily life.

15. The circulation during exposure to heat and cold. When the skin is exposed to cold its blood supply is greatly diminished; the veins no longer stand out prominently on the hand, and if a small area of skin be made pale by pressing upon it (thus driving the blood out of its capillaries), the pallor passes off very slowly. This simple experiment shows that blood is flowing but slowly from the arterial reservoir into the skin. Conversely, on a warm day the veins stand out prominently and the red color instantly returns upon the removal of pressure. These variations in the supply to the skin are due, as we have already seen (p. 147), to changes in the diameter of the arteries of the skin, which changes serve, like the spigot of an ordinary water faucet, to regulate the flow of liquid.

The changes in the blood flow through the skin are accompanied by corresponding but inverse changes in the internal organs. On a cold day the stomach and intestines, the pancreas, the liver, the kidneys, etc. are richly supplied with blood, while on a warm day their blood supply is diminished. In the former case the blood withheld from the skin finds its way into the internal organs; in the latter case the skin draws upon these organs for its needed supply. The circulation in the internal organs *compensates* for that in the skin.

16. The reason for compensatory changes. We have seen that it is the function of the heart to keep the arterial reservoir adequately distended with blood, thus supplying a steady driving force for the flow of blood through the organs. When the small arteries of the skin widen on a warm day, blood escapes more rapidly into the skin from the arterial reservoir. This alone would diminish the amount of blood in the reservoir unless the heart pumped more blood or unless the dilation or widening of the cutaneous arterioles were *compensated* by a constriction elsewhere, so that the total drain on the reservoir remained the same. In the case in question it is the latter of these alternatives which is adopted, and the reservoir is kept filled without calling on the heart to pump more blood.

Conversely, on a cold day the diminution of the outflow into the skin would lead to a backing up or accumulation of blood in the great arteries, and so to their increased and perhaps undesirable distention, if the dilation of the arterioles of internal organs did not provide an outlet for the surplus blood.

Nowhere, perhaps, is this principle of compensatory dilation or constriction of arteries in one region, to allow for the effect of the opposite change in some other region, so highly developed or so fully applied as in the reactions of the body to changes in external temperature.

17. The circulation during muscular activity. During muscular activity the arterioles of the muscles and of the skin are dilated, the former in order to supply more blood to the working organ, the latter to aid in the discharge of the excess of heat produced by the contracting muscles. The heavy drain upon the arterial reservoir by these two large areas (among the largest in the body) is compensated to some extent by the constriction of the arteries of the digestive and other internal organs. This alone, however, would not suffice to keep the arterial reservoir filled; and we accordingly find that the heart beats more rapidly and more powerfully, pumping more blood into the aorta in a given time.

It is very important to remember that muscular activity is the one condition of life which materially increases the work of the heart; at other times the greater demand of blood for the working organ is met more or less successfully by withdrawing blood from a resting organ, while the supply to the whole arterial system, and hence the work of the heart, remains approximately unchanged. During muscular exercise, and then only, is the heart called upon for decidedly increased work; and, as with skeletal muscles, its strength, its ability to meet strain and emergencies and to withstand fatigue, depend to a great extent upon the training given it in this way.

Muscular activity also influences the circulation indirectly by increasing the action of its secondary driving forces — the suction action of the respiratory movements and the pumping action of the contracting muscles on the veins. These are among the most important effects of this agent upon the flow of blood, but they are too complicated for detailed discussion here.

It is sometimes stated that muscular exercise "quickens" the circulation. This is true in the sense that the heart pumps more blood into the pulmonary artery and the aorta than during rest. From this it follows that during exercise more blood flows through the lungs and that blood flows more rapidly out of the arterial reservoir, but it does not mean that blood flows more rapidly through all organs, for the digestive and other internal organs at such times actually receive less blood. Indeed, we may say that the quickening

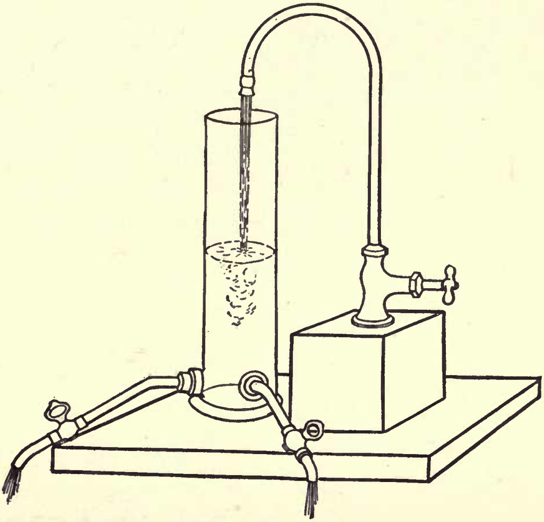


FIG. 74. Simple apparatus to illustrate the relation between the output of the heart, the peripheral resistance, and the general arterial pressure

The amount delivered by the faucet represents the output of the heart, and is one factor in keeping up arterial pressure; two alternative routes of outflow, each capable of regulation, represent the arterioles to different organs. Compensatory constrictions and dilations and other hydraulic conditions described in the text may readily be imitated

of the circulation during exercise is chiefly confined to three important organs — the muscles, the skin, and the lungs; in other organs the change is relatively slight, as, for example, in the brain; while in still others, notably those of the digestive system and the kidneys, the speed is diminished.

18. The circulation during sleep. An adequate blood supply is necessary to the full activity of the brain; when the circulation in this organ is seriously interfered with, imperfect mental action or even unconsciousness is a result. Thus when all the arterioles of the body dilate, or the heart beat is slowed down, in consequence of some sudden "shock," so that pressure in the arterial reservoir falls too far, the driving force for the flow of blood through the brain, as well as through other organs, is diminished, and the person loses consciousness, or faints. Most cases of fainting are traceable to one or the other of these causes.

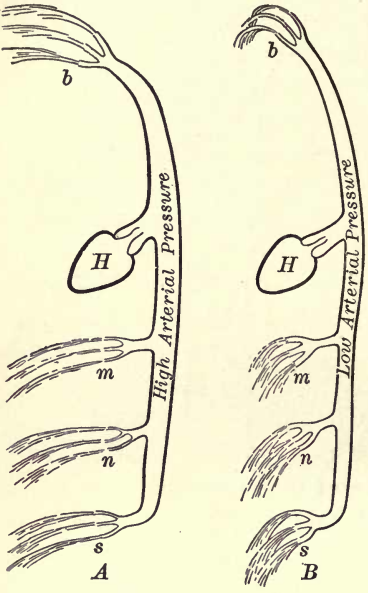


Fig. 75. Showing the relation between general arterial tone and the supply of blood to the brain

In *A* the arterioles of the organs *m*, *n*, *s* are constricted, raising general arterial pressure, which forces a large amount of blood through the brain *b*. In *B* the arterioles of *m*, *n*, and *s* are dilated, general arterial pressure is low, and less blood is forced through the brain. *H*, heart

The most familiar and most common example of unconsciousness, however, is that of sleep, which in so many respects resembles fainting as to suggest that the unconsciousness in both cases is due to the same cause, namely a lessened blood supply to the brain. Unquestionably, the amount of blood flowing through the brain is greatly lessened during sleep. The evidence for this statement cannot be given here in full, but it is known that where accident has destroyed a part of the rigid bone of the skull, and the wound has been covered over by connective tissue and skin, the scar sinks in during sleep — indicating less blood in the brain — and returns to the level of the general surface of the head when the subject awakens.

Upon this point of diminished blood supply to the brain during sleep almost all physiologists are agreed; there is also general agreement that the arm and the leg increase in volume when we go to sleep, and this is thought to be due to a dilation of the arteries of the skin. It is very significant, on the other hand, that the arm shrinks in volume when the brain is active in mental work, and especially in mental work involving the personal interest or mental concentration of the subject of the experiment.

It is thought by some that other vascular areas — that of the abdominal cavity, for example — behave in this respect in the same way as the skin, but on this point the evidence is not conclusive. It is, indeed, not improbable that these other vascular areas play some part in the regulation of the flow to the brain, but it is not likely that they stand in the same intimate relation to it as does the skin.

The fact is clear, however, that a close relation exists between cutaneous circulation and the maintenance of proper vascular conditions in the brain. Mental work, for example, is more difficult for most people in very warm weather because at that time the cutaneous arterioles are widely dilated; and, on the other hand, it is easy to understand why the constriction of the vessels of the skin by cold makes it difficult to go to sleep without sufficient bedclothing.

19. The circulation during the digestion of a meal. After eating a meal more blood is needed in the secreting digestive glands (especially the stomach and pancreas) and also in the intestinal organs of absorption, the villi. This need is greatest during the first hour or two, when there is the largest amount of food to be worked upon. We find, accordingly, that the arteries of these organs then dilate to such an extent that the mucous membrane of the stomach and intestine, which is pale pink while those organs are at rest, now becomes very red on account of the large amount of blood flowing through them.

There is probably some compensation for this in other organs, but it is an imperfect compensation. The drowsiness which is apt to come on after a hearty meal is probably an indication that these compensations are not complete and that owing to the fall of arterial pressure the brain is not receiving its normal blood supply.

20. Some practical applications. We may pause here to consider some important practical applications of these facts. While the most active secretion is in progress nothing should be done which will take blood away in large quantities from the stomach. Muscular exercise, for example, then as always, dilates the arterioles of the muscles and skin and *constricts those of the digestive organs*; this is obviously an unfavorable vascular condition for the act of secretion. If the meal be a light one, so that comparatively little of the digestive juices are required, no harm may be done by taking exercise after a meal; but where the meal is heavier it is almost always unwise, especially in warm weather. Similar considerations, which are likewise in full accord with experience, indicate that it is unwise to eat as large meals in very warm weather as in cooler weather. The larger the meal, the greater the amount of gastric juice required to start its digestion; but in warm weather the arteries of the stomach and intestine tend to be constricted (see p. 152), so that it is difficult to secure an adequate blood flow through these organs, and their efficiency is to this extent impaired.

It is sometimes stated that mental work immediately after meals causes indigestion by taking blood away from the digestive organs and sending it to the brain. It is very doubtful, however, whether the increased blood flow to the brain is secured largely at the expense of that to the digestive organs. While instances might be cited of indigestion among people who do mental work upon a "full stomach," it must be remembered that these are usually people who fail to take proper exercise or sufficient sleep and rest; the indigestion from which they too frequently suffer is more often attributable to these causes than to the fact that the digestive organs are deprived of their proper blood supply.

21. The mechanism of the regulation of the flow of blood. Having thus considered exactly what takes place in the circulation during some of the more important events of daily life, we may next inquire briefly into the physiological mechanism by which these adjustments are secured. Its most important features are the regulation of the inflow from the heart into the arterial reservoir and the regulation of the outflow through the arterioles and capillaries of the organs. These two must be adjusted to each other in order that the reservoir may remain full and thus the driving force for the flow through the organs be maintained. We shall go into the details of this very beautiful but complicated mechanism only far enough to enable the student to appreciate certain principles of fundamental importance in the practical conduct of life.

22. The regulation of the pumping action of the heart. The amount of blood which the heart pumps varies considerably from time to time. At times it may be as low as three quarts a minute and at other times as high as twelve quarts, the quantity being largely determined by the drain made at the time upon the arterial reservoir. It will be seen at once that this involves a wide range of adjustment.

The beat of the heart is primarily due to events which take place within the heart itself. We have seen that this beat is a muscular contraction. But the cardiac muscle differs from the skeletal muscle in that it does not require an impulse from the central nervous system to throw it into activity. When the heart is cut off from connection with the rest of the body, it continues to beat for a time and, if supplied with warm blood, it may be kept beating for hours.

We express this by saying that the heart beat is *automatic*, by which we mean that the heart contains within itself a complete mechanism for doing its own work.

23. The augmentor and the inhibitory nerves of the heart. Nevertheless the heart receives from the central nervous system two pairs of nerves which are able to influence the rate and the force of the automatic beats. One pair of these nerves carries from the spinal cord to the heart impulses which stimulate that organ to beat more rapidly or more forcibly, or both. Hence these are known as the *augmentor*, or *accelerator*, nerves.

The fibers of the other pair of nerves produce exactly the opposite effect. Running from the lower part of the brain, they carry to the heart impulses which slow the beat or lessen its force, or they may produce both effects at the same time. They act, as it were, like a brake on a wheel, checking the activity of the automatic beat. These fibers are known as *inhibitory* fibers, and their action is a case of *inhibition.*

24. Inhibition. In the examples of nervous action which we have thus far studied, the nervous impulse has uniformly thrown some cell into *activity.* The stimulation of muscle fibers to contract, of gland cells to secrete, and of nerve cells in the execution of reflexes will be readily recalled. To this same class of nervous actions must now be added that of the augmentor nerves of the heart, for they excite the heart to greater activity.

In the inhibitory nerves, on the other hand, the nervous impulse produces exactly the opposite result. Instead of setting organs to work or stimulating them to more vigorous action, they diminish activity and in extreme cases check or stop it altogether. In our subsequent studies we shall meet with many examples of this effect; but we may say at once that inhibition is as characteristic and as important a feature of the nervous system as is excitation (see p. 281).

25. The regulation of the outflow from the arterial reservoir; arterial tone. Wound around the walls of the arterial tubes, especially the smaller arteries (arterioles) which deliver blood from the arterial reservoir to the organs, are peculiar muscle fibers. Their contraction diminishes the size and bore of the tube, and, when they relax, the tube and its lumen become wider. As a usual thing these smaller arteries are kept somewhere midway between extreme constriction and extreme dilation. On a day of moderate temperature, for example, the arterioles of the skin are moderately narrowed by this action of their muscle fibers. During colder weather these fibers contract more than usual and so lessen the size of the tube, while during warm weather they relax somewhat and widen it; but ordinarily they are never contracted to their utmost nor are they often completely relaxed.

This condition of sustained activity of the arterial muscles is known as *arterial tone*, and in general any sustained activity of a living cell is spoken of as *tonic activity*, or *tone*. Since, as we have seen, the total quantity of blood in the body is not enough to fill completely and distend all the blood vessels when they are widened to their utmost, it follows that the maintenance of arterial tone is essential to that overfilling of the great arteries which supplies the driving force for the flow of blood through the organs. If every arteriole were to lose its tone, blood would flow out of the reservoir more rapidly than the heart could possibly pump it in; we should have somewhat the same condition of affairs as if, in our artificial model (p. 144), the small nozzle which affords resistance to the outflow were removed. Arterial pressure would fall and, the driving force being thus removed, the blood would remain at rest in the capillaries and veins of the organs; the circulation would cease because blood would not return to the heart to be pumped. The maintenance of arterial tone is consequently no less essential to the circulation than is the beat of the heart itself.

Two means are known by which the contraction of the circular muscle fibers of the arterioles is regulated: first, impulses from the central nervous system over the *vasomotor* nerves; and, second, direct excitation of the arterioles by hormones in the circulating blood. The vasomotor nerves are of two kinds, the vasoconstrictors and the vasodilators; the best-known hormone acting on the arterioles is adrenaline, the action of which has already been referred to in Chapters VI and VII.

26. Vasoconstrictor nerves. The muscle fibers of the arteries receive nerves which stimulate them to contract, for if these nerves are cut, the arteries lose their tone (dilate). We conclude, therefore, that the ordinary maintenance of arterial tone is, in part at least, a function of the nervous system. The muscle fibers of the arteries, in other words, remain in tonic activity because the neurones which supply them with nerve fibers are in tonic activity; and we can understand how general arterial tone may be increased or decreased by the condition of the central nervous system, by reflexes, by the nervous "shock" of surgical operations, etc.

Neurones which maintain the proper amount of arterial tone are known as *vasoconstrictor* neurones. They obviously do for the muscles of the arteries what the motor nerves do for the skeletal muscles, and the augmentors do for the heart.

27. Vasodilator nerves. Many arteries, however, receive a second set of nerves, which have exactly the opposite function, that is, to make their muscle fibers relax and so lead to a widening or dilation of the artery. These nerves do for the tonic contraction of the arteries what the inhibitory nerves of the heart do for the heart beat — they diminish or abolish an existing activity and thus give us our second example of inhibitory nerves. They are known as the *vasodilators.*

The vasodilators are not regularly in tonic activity like the vasoconstrictors. They are called into action, reflexly or otherwise, when it is necessary that an organ receive more blood than usual; at other times the vasoconstrictors are free to exert their tonic stimulation and so regulate the flow of blood to the organs.

28. The regulation of arterial tone by hormones; adrenaline. This has already been described on page 65. It will be recalled that the presence of adrenaline in the circulating blood directly excites the arterioles to constrict; that this action on the arterioles is greater in some regions (for example, the abdominal organs) than in others (for example, the skeletal muscles and skin); that the rate and force of the heart beat are influenced; that the adrenal glands are excited to secrete by nervous impulses which are dispatched from the central nervous system during states of emotional excitement (fear and anger) and, we may now add, whenever the blood is deficient in oxygen. There are also reasons for thinking that the internal secretion of the pituitary body (p. 67) may likewise play some rôle in regulating arterial tone and possibly in the distribution of the blood among the organs. This is a new field of physiology and the present state of our knowledge justifies only this brief reference to it. Enough is known, however, to show that hormones coöperate with the vasomotor nerves in regulating the flow of blood to the organs.

29. Importance of the vascular adjustments in daily life. It is not possible within the limits of the present work to enter further into the mode of action of these factors of vascular coördination. Our main purpose is to show the student that proper coördination is as important in adapting the work of the heart and blood vessels to the hourly needs of daily life as it is in producing purposeful movements of the skeletal muscles. Every change of occupation and activity, every change of surrounding conditions of temperature, moisture, wind, etc., necessitates some special adjustment of the vascular system; and this adjustment is dependent upon the same sort of coördinating action which we have already compared with the operations of a large army. In spite of the fact that we are for the most part unconscious of it, it is none the less a part of our daily life; and the fatigue induced within these vasomotor and hormone mechanisms by their continued activity probably contributes a large share to that general bodily fatigue which leads us to seek recuperation in rest and sleep.

The apparatus, the operation, and the regulation of the flow of blood and lymph afford an excellent illustration of the fact that the human body, at least in this particular, is a complex machine. But while we of to-day look upon it with somewhat less of awe than did our ancestors, and while there is for us less of mystery and more of mechanism in it, we gain, on the other hand, a wholly new revelation of its intricacy and a fresh sense of its marvelous delicacy, beauty, and perfection of adjustment. The mere fact that everyone of us carries in his bosom a powerful double force-pump of remarkable design, original construction, and extraordinary power, capable in many instances of successful and unremitting service for more than three quarters of a century, should be, in itself alone, enough to excite admiration and respect for the entire mechanism of which it is only one part and to awaken within us a desire to use that mechanism "as not abusing it."

CHAPTER X

RESPIRATION

1. The fundamental act of respiration. We have found in studying the chemical changes which underlie cellular activity (Chap. IV) that muscle fibers and gland cells and, we may now add, nerve cells take in oxygen and give out carbon dioxide. This *cell breathing* is the essential act of *respiration*, for respiration is only another name for the oxidative processes of the living body. Respiration of this kind (and of this kind only) is universal among living things. The one-celled animal, for example, takes its oxygen directly from the free oxygen of the water in which it lives, and discharges its carbon dioxide into the same surrounding medium. Every one of the thousands of cells of which the human body is composed repeats this same process, taking its oxygen from and discharging its carbon dioxide into its surrounding medium — in this case the lymph. The breathing movements, which renew the air in the lungs, and the circulation of blood, which affords the channel of communication between the lungs and the tissues, are merely accessory mechanisms rendered necessary by the distance of the cells and the lymph from the surface of the body. Their principal function is to keep the lymph supplied with oxygen and to remove from it the carbon dioxide. In other words, breathing, though ministering to respiration, is not respiration itself.

2. The quantity of oxygen and of carbon dioxide in the lymph surrounding the cells of the body. The cell is the true seat of oxidation. Within its imperfectly understood mechanism are found the conditions which lead to the union of oxygen with the proteins, the carbohydrates, and the fats of the food.

The cell draws oxygen from the surrounding lymph very much as a burning match draws oxygen from the surrounding air. Consequently the amount of oxygen dissolved in the lymph is generally comparatively small and would be removed altogether were it not constantly renewed from the blood.

For similar reasons the lymph must be relatively rich in carbon dioxide, since it is this fluid which directly receives the gas (in solution) from its source of manufacture, the working cell.[1]

3. The quantity of oxygen and of carbon dioxide in arterial blood. It is through the lungs that the body as a whole receives its oxygen and discharges its excess of carbon dioxide. Consequently arterial blood contains more oxygen and less carbon dioxide than venous blood. The actual figures are as follows:

	Oxygen	Carbon Dioxide	Nitrogen
100 cc. of arterial blood contain	20 cc.	38 cc.	1–2 cc.
100 cc. of venous blood contain	8–12 cc.	45–50 cc.	1–2 cc.

These figures apply to the whole blood, that is, to plasma and corpuscles; but what is true of the whole blood is true in a general way also of the circulating plasma, which consequently enters the capillaries[2] relatively rich in oxygen and poor in carbon dioxide, thus presenting exactly the reverse composition, in respect to these gases, of that found in the lymph surrounding the living cells.

[1] The gases oxygen and carbon dioxide are, of course, dissolved in the liquid lymph and blood plasma. A liquid exposed to a gas absorbs or dissolves the gas. Thus 100 cc. of water when exposed to atmospheric air at 0° C. dissolves 4 cc. of oxygen and 2 cc. of nitrogen.

[2] The total time consumed by the blood in passing from the capillaries of the lungs through the heart to those of the rest of the body seldom exceeds five or six seconds. Hence the amount of the gases in the blood entering the capillaries, for example, of a muscle is practically the same as in the blood leaving the lungs.

4. The exchange of oxygen and carbon dioxide between the lymph and the blood plasma. In the capillary regions of all parts of the body except the lungs we have two fluids, the lymph and the blood plasma, containing very different amounts of oxygen and carbon dioxide and separated from each other by the exceedingly thin membrane of the capillary wall. Under such conditions both gases will tend to equalize, and each gas will pass through the membrane from that liquid in which it is more abundant to that in which it is less abundant; that is to say, the oxygen will pass from the blood plasma in which it abounds to the lymph in which it is scarce; and the carbon dioxide, in the other direction, from the lymph to the blood plasma (see Fig. 76). Hence the blood enters the veins richer in carbon dioxide and poorer in oxygen than it left the arteries.

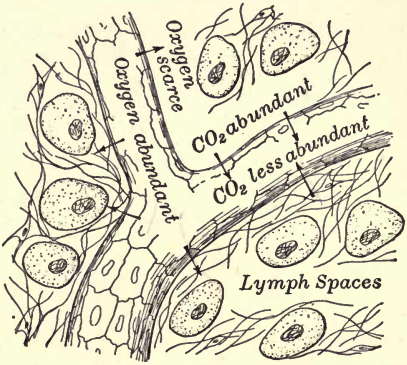


FIG. 76. The exchange of oxygen and carbon dioxide between the blood and the lymph in the tissues

5. The red corpuscle as a carrier of oxygen. The blood plasma under the conditions of temperature and pressure to which it is exposed can hold only a small amount of oxygen, too little to meet satisfactorily the demands of the resting tissues and utterly inadequate for the much greater needs of the working tissues. This difficulty is met and the oxygen-carrying capacity of the blood vastly increased by the peculiar properties of the coloring matter, or pigment, of the red corpuscles. This substance, known as hemoglobin, readily forms with oxygen a compound (*oxyhemoglobin*) *whenever the amount of oxygen is high in the medium surrounding it*; if, however, much oxygen is removed from its surrounding medium, the oxyhemoglobin breaks up or dissociates into hemoglobin and free oxygen. Applying this to the conditions in the capillaries, we find that 100 cc. of arterial blood contain less than 1 cc. of free oxygen in the plasma, but about 19 cc. of oxygen combined in the oxyhemoglobin of the red corpuscles. When the blood enters the capillaries of living tissues, oxygen passes, as we have seen, from the plasma into the lymph, so that the oxygen content of the plasma is reduced. When this reduction goes below a point which is quickly reached, dissociation of the oxyhemoglobin occurs, and the oxygen thus set free in the plasma is drawn away by the lymph, from which it is in turn drawn by the cell, the real seat of oxidation.

The amount of oxygen given above (20 cc. to 100 cc. of blood) is all that the blood can hold under the usual conditions of atmospheric pressure and at the temperature of the body. Moreover, the oxygen content of the blood leaving the lungs (arterial blood) is usually kept remarkably constant by the accurate adjustment of the breathing movements to the needs of the body. Neither by deeper nor by more rapid breathing is it possible to increase appreciably the amount of oxygen absorbed by the same volume of blood flowing through the lungs. Only by increasing the quantity of blood pumped through the lungs can we increase the amount of oxygen carried to the organs and tissues; and, for the same reason, only by increasing the quantity of blood flowing through an organ can we increase the oxygen supplied to that organ.

6. The consumption of oxygen in the tissues. The quantity of material oxidized in the cells of the body depends chiefly, indeed under ordinary conditions of life it depends entirely, on the amount of work these cells are doing. To put the matter in another way, the cells always contain a certain quantity of oxidizable material formed by the chemical changes going on within them; during work, or activity, there is a marked increase of oxidizable material (possibly the result of the cleavages described in Chapter IV), and for this reason there is a corresponding increase of oxidation in the cell. It follows that, in general, cell oxidation can be increased only by increasing cell work; it cannot be increased by the mere act of deep breathing. "We may lead a horse to water or fetch water to a horse, but we cannot make him drink." The assertion, too frequently heard, that some special form of breathing movement leads to more efficient oxidation of wastes throughout the body betrays lamentable ignorance of this fundamental fact of physiology. This, however, is not denying that one type of breathing movement may still be preferable to another, nor affirming that deepened breathing may not sometimes be desirable. Breathing movements accomplish other things than oxygenation of the blood, and we may now proceed to study their physiology.

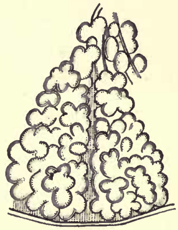


FIG. 77. Two adjacent alveoli of the lung

Showing the air cells

7. Structure of the lungs. In Chapter II the anatomical relations of the air passages (*trachea*, *bronchi*, etc.) and lungs have been described. The student at this point should consult especially Fig. 5 (p. 13) in order to obtain a clear idea of the structure of the lungs. The bronchi which enter the lungs branch, much as the ducts of a gland, and their ultimate branches end in the *alveoli*, which, like those of a gland, consist of a single layer of cells, but in this case of *very thin, flattened cells.* Fig. 77 shows two of these alveoli dissected, and Fig. 78 a section taken lengthwise through the same. Connective tissue binds together the alveoli and bronchial tubes, thus forming the lobes of the lungs. In this connective tissue—and hence between the alveoli—are the larger blood vessels, branches of the pulmonary artery and pulmonary veins. The arterioles supply an exceedingly close network of capillaries (Fig. 159), which are in direct contact with the lining cells of the alveolus, so that the blood in these capillaries is separated from the air in the alveolus only by the thin capillary wall and the equally thin layer of flattened alveolar cells. Under these circumstances the exchange of oxygen and carbon dioxide takes place readily between the air in the lungs and the blood in the capillaries. Finally, the absorbing surface of the alveolar wall is greatly increased by being arranged in the form of pits, or *air cells*,[1] as shown in Figs. 5, 77, 78, and 159.

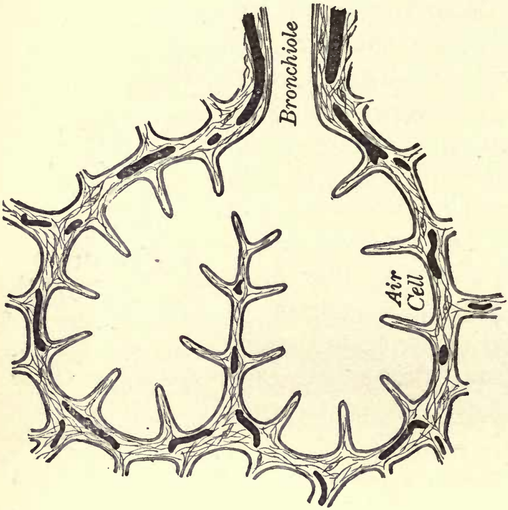


Fig. 78. Diagram of a longitudinal section of two alveoli with their common bronchiole, and showing, in black, the larger blood vessels in the connective tissue

The capillary network belonging to these vessels is shown in Fig. 159

8. Purpose of breathing movements. As the blood is constantly giving up carbon dioxide to, and taking oxygen from, the air of the lungs, this air would soon cease to be of use in purifying the blood were it not for the breathing movements, whose function is to replace the vitiated air within the lung with pure air from without. Breathing is, accordingly, an act of *ventilation* of the lungs, and it is the stoppage of this ventilation which produces suffocation, or asphyxia.

[1] The word "cell" is here used to represent a hollow space and not with its usual histological meaning.

9. Mechanics of the breathing movements. A knowledge of the mechanism of the breathing movements is of much practical importance, especially in hygiene, and may be understood without great difficulty by the study of the model shown in Fig. 79. The trachea and the bronchi are represented by the glass tube, and the lungs by an elastic bag, *L*, at the end of the tube. The lungs lie in the large *air-tight* thorax, which incloses the *pleural*, or *thoracic*, *cavity* (p. 10). This thoracic wall is represented in the model by a glass bell jar closed beneath by a sheet of thick rubber, *D*. The cavity of the bell jar represents the pleural cavity, and the rubber represents the diaphragm (see Fig. 154). The condition of the lung in the pleural cavity may be still further imitated in the model by fastening the *inflated* rubber bag tightly into the jar.[1] The rubber bag remains moderately inflated within the air-tight cavity of the bell jar. In the body the distended lungs virtually fill those portions of the thoracic cavity not occupied by the heart, great blood vessels, and other organs.[2]

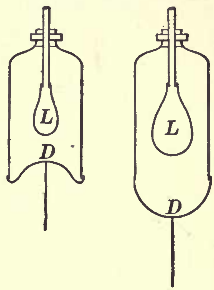


FIG. 79. Model of the action of the thoracic walls and lungs in respiration (see sect. 9)

Now enlarge the "thoracic cavity" of the model by pulling downwards on the sheet of rubber which represents the diaphragm. The "lungs" within will expand while air is sucked through the glass "trachea" and mixes with that in the model "lungs." When the pull is released, the "diaphragm" rises, thus diminishing the size of the "thorax" and so forcing air out of the "lungs." In this way the mechanism of the ventilation of the lungs may be imitated in essential particulars.

[1] Loosen the rubber stopper and, while the neck of the bell jar is open, inflate the rubber bag through the tube; while the bag is thus inflated, push the rubber stopper down into the neck of the bottle.

[2] The student is again warned against supposing that the pleural cavity is a large space filled with air; in this respect the model is misleading, since the lungs and other organs *completely* fill the thoracic cavity.

In life the pleural cavity is enlarged during inspiration by the contraction of the diaphragm and the elevation of the ribs. Both of these are movements effected by the action of skeletal muscles. The understanding of the elevation of the ribs need give no difficulty; muscles, some of which are shown in Fig. 12, pull upwards on the ribs; and the attachment of the ribs to the vertebral column and the breastbone (sternum) is such that when they are raised the diameter of the thorax is increased dorsoventrally and from side to side. The diaphragm, on the other hand, is a kind of circular muscle with a central fibrous or tendinous portion from which the bundles of muscle fibers radiate outwards to its edges. Any shortening of these fibers evidently diminishes the diameter of the diaphragm; and because of its form (that of a dome directed upwards into the thoracic cavity), contraction of this muscle must increase the size of the lower thorax.[1]

There are three typical modes of breathing: (1) *The predominantly costal, or "rib," breathing.* Here the diaphragm is but little used. It is the type characteristic of those who impede movements of the lower ribs and abdomen with constricting clothing, such as tight corsets. (2) *The predominantly abdominal.* Here the ribs are little used, while the diaphragm does most of the work, the abdominal muscles being relaxed so that the belly wall has its maximum of movement. This type of breathing involves great relaxation of tone of the abdominal muscles, which is a serious

[1] The action of the diaphragm is often described as increasing the antero-posterior (head to foot) dimension of the thorax; but this can happen only when the diaphragm is free to descend, and it can descend only when, by displacing downwards the contents of the abdominal cavity, it causes the well-known respiratory movements of the abdominal walls. These "abdominal movements" may, however, be prevented by the simultaneous contraction of the abdominal muscles. In this case the diaphragm cannot descend, and its contraction can only raise the lower ribs to which it is attached. The mechanism in these two methods of using the diaphragm is clear from Fig. 80.

disadvantage. (3) *The lateral costal.* Here the abdominal muscles act at the same time as the ribs and the diaphragm. This form of breathing produces the highest pressures on the contents of the abdominal cavity and maintains the tone of the abdominal walls without diminishing the efficiency of the oxygenation of the blood. It also forces the

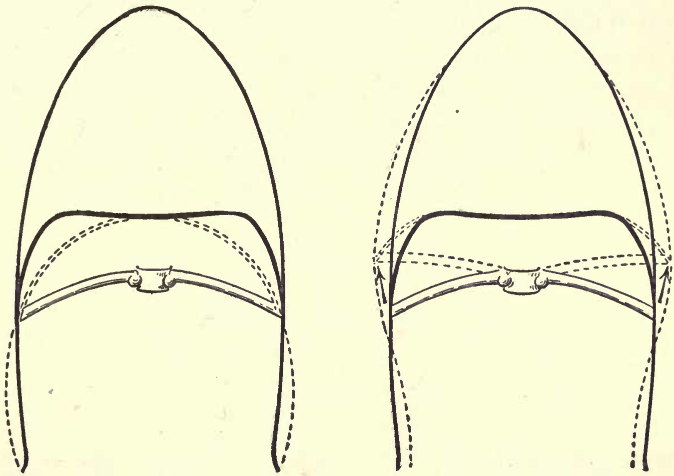


FIG. 80. Action of the diaphragm in abdominal and in lateral costal breathing

Solid lines represent position of body wall, diaphragm, and ribs during expiration; dotted lines, the same during inspiration. The left-hand figure represents abdominal breathing, the diaphragm becoming more convex, displacing downward the abdominal viscera and forcing outward the abdominal body wall. In the lateral costal type the diaphragm raises the lower ribs, and the abdominal walls may actually move inward, owing to the contraction of their muscles

use of the upper ribs to a much greater extent than does the predominantly abdominal type of breathing (Fig. 80).

It is seldom that one or another of these types is used in its entirety, and the advantages of one form over another are often greatly exaggerated. The following statements may, however, be taken as summing up the essential practical points.

1. *The breathing movements should be such as to use all portions of the lungs.* In the abdominal type there is little or no movement of the upper thorax. The result is that the apical, or upper, lobes of the lungs do not share in the enlargement and contraction of the lungs; they are poorly ventilated, their lymph current — which largely depends upon these movements — becomes sluggish, and because of these unfavorable physiological conditions there is greater liability to disease. More than 60 per cent (some observers claim, as many as 80 per cent) of the beginnings of the lung ravages of pulmonary consumption are found in this portion of the lung, and this is believed to be due to the lack of movement which results from the failure to use the upper thorax.

2. Actual study of the breathing movements in people who have not worn constricting clothing indicates that the enlargement of the thorax in inspiration is effected by the approximately equal action of the diaphragm and of the muscles which elevate the ribs.

3. The abdominal muscles should to some extent contract with the diaphragm. This is especially important in those whose occupation is more or less sedentary, as it is the most convenient means of giving to these muscles the use which is essential to the maintenance of their strength and the consequent prevention of that loss of tone which takes away from the organs of the abdominal cavity one of their chief supports (consult Part II, Chap. XVIII).

4. There are good reasons for thinking that it is important to develop properly the muscles of the upper thorax and especially those which lie in the triangle between the root of the neck, the collar bone, and the shoulder blade. When these muscles are not developed, especially in thin people, the wall of the thorax in this region sinks inward during inspiration; under these circumstances this portion of the thorax is not enlarged during inspiration, the apical lobes no

longer share in the expansions and contractions of the lungs, and imperfect ventilation of this part of the lung results.

10. Secondary effects of the breathing movements. The student will now be better able to understand the part taken by the breathing movements in facilitating the return of blood and lymph to the heart. The enlargement of the thorax during inspiration sucks blood and lymph in toward the great veins by the same process that it sucks air into the lungs. Especially in the case of the lymph flow is this a most important factor. Moreover, in the lymphatics of the lungs, situated as they are entirely within the thorax, the movements of the lungs during respiration pump the lymph onwards and are of special importance in this respect. Much of the invigorating effect of muscular exercise, popularly ascribed to better oxygenation of the blood and tissues, is really attributable to the greatly improved lymph flow from all organs which results from the deepened respiration in muscular activity.

11. The automatic respiratory center and its regulation by the carbon dioxide of the blood. The muscles of the diaphragm and those of the ribs, like the biceps and other muscles which act upon the skeleton, are stimulated to contraction by nervous impulses from the brain and spinal cord. Every movement of respiration is called forth and regulated, in accordance with the needs of the body at the time, by the coördinated action of a number of nerve cells. Those which are most intimately concerned with respiration are found in different parts of the central nervous system, from the lower portion of the brain to the end of the first half of the spinal cord, inclusive; and there is good reason for thinking that a group of nerve cells, usually known as *the respiratory center*, in the lower portion of the brain, send out stimuli to those of the cord and through them excite the muscles to contract.

The respiratory center, like the heart (see p. 159), is automatic. This means that its nerve cells periodically (usually eight to twenty times a minute) discharge impulses to the respiratory muscles independently of any stimulation either by afferent nerves or by other means. Like the beat of the heart, however, this automatic action is regulated in various ways. A dash of cold water on the skin reflexly changes the character of respiration; coughing and sneezing are similarly examples of reflex modification of the breathing movements; during vigorous muscular activity the change in composition of the blood by the addition of waste products deepens and quickens the breathing; last, but not least, one of the most important discoveries of recent years has shown that the carbon dioxide of the arterial blood going to the respiratory center is a most important agent in regulating the automatic activity of the center. No sooner does the carbon dioxide of the blood increase than the center discharges more powerfully, thus deepening the breathing. An increase of from 3 to 4 per cent in the carbon dioxide of the arterial blood doubles the quantity of air breathed per minute. From this it is evident that the high content of this gas in arterial blood (see p. 166) serves the very important function of adjusting the work of the center to the needs of the body. Whenever, for any cause, the respiratory movements no longer adequately ventilate the lungs — so that carbon dioxide discharged upon the blood in its course through the body is not completely removed in the lungs — the consequent increase of this gas in the arterial blood excites the center to greater activity, with a resulting increase of breathing and more efficient ventilation of the lungs. We may recall, in this connection, the warning given in Chapter VI against supposing that a "waste product" of the activity of one organ is necessarily harmful, for carbon dioxide is the chief waste of the body; yet it is most important that the amount usually present in arterial blood be maintained. Only the excess above this amount is injurious.

12. The circulation as an essential part of the mechanism of respiration. The consumption of oxygen and the production of carbon dioxide thus involve an interchange of these gases between the blood and the tissues (internal respiration) on the one hand, and between the blood and the air in the lungs (external respiration) on the other. But to carry out these gaseous exchanges a third factor is obviously necessary, namely, a means of communication between the two, so that the oxygen absorbed in the lungs may be carried to the tissues, and the carbon dioxide produced in the tissues be carried back to the lungs. This communication is provided, as has been shown in earlier chapters, by the circulation, which thus becomes an essential part of the respiratory mechanism.

We have already seen that under the most varying conditions 100 cc. of arterial blood always contain approximately 20 cc. of oxygen and 38 cc. of carbon dioxide and that this is practically all the oxygen this amount of blood can hold. From this it follows that so long as the amount of blood pumped by the heart in a given time remains constant, no more oxygen will be carried to the tissues, even if we breathe more deeply. In other words, *increased ventilation of the lungs without any accompanying increase in the rate and force of the heart beat will not supply more oxygen to the tissues.* The beat of the heart is as important to proper tissue respiration as are the breathing movements; and we find accordingly that these two events are closely coördinated. Greatly increased tissue respiration invariably carries along with it increased work on the part of the heart.

A large number of measurements of the respiratory exchanges[1] under different conditions and activities of our life has shown that these are increased by the taking of food, by exposure to cold, by awaking from sleep, and, above all, by muscular activity. Exposure to cold acts by

[1] That is, oxygen absorbed and carbon dioxide discharged in a given time.

causing us to move about more briskly, or, if we do not, by causing us to shiver, so that this really becomes a case of muscular activity. The same thing is true of awakening from sleep. We may therefore make the general statement that muscular activity is the one important agent of life which increases tissue respiration.

And this increase is at times very great. Even the muscular activity necessary to maintain the erect position in sitting and standing, as compared with the complete relaxation of sleep, doubles the gaseous exchange; gentle exercise (a walk of three miles an hour) more than doubles that of rest; and vigorous, yet by no means excessive, exercise will increase it tenfold. These increases mean corresponding, though not absolutely proportionate, demands on the heart and emphasize the importance of keeping that organ in an efficient working condition. Breathlessness, for example, usually indicates, in part at least, that the heart fails to respond properly to the demands made upon it, these demands being greater than it can meet without undue fatigue; it is a warning that we are pushing the heart too hard, a warning which we will do well to heed. Generally it is also a warning that we are not getting sufficient muscular activity; the heart fails to meet the emergency of some unusual exertion because all along it has not been kept in proper training; so that while we should, as stated, heed the warning not to push the heart so hard for the time being, we should also act upon the equally important warning that it needs practice or training — a training which can be given only by reasonable, regular, muscular activity.

The training of muscular activity is therefore not only a training of the muscles but also of the heart. But this is not all. *The work of the circulatory and respiratory mechanisms must be adjusted or coördinated, the one to the other.* When, for example, the deepened breathing movements accompanying muscular activity rush the blood back more rapidly to the heart (p. 148), it becomes necessary for the heart to adjust the character of its beat to the new conditions; and this adjustment is the work of the nervous system. Time is, however, required to make the adjustment, so that it is wise to "warm up" gradually to more vigorous work. We can also understand how by physical training this process of adjustment comes to be shortened, for we have not only trained the heart by giving it more work to do but we have also trained those portions of the nervous system which regulate its beat.

CHAPTER XI

EXCRETION

1. The organs of excretion. The student now realizes that the work of the body is accompanied by the production of wastes and also understands the necessity for their removal. The most abundant waste product of the body, carbon dioxide, is a gas and is excreted by the lungs; others, notably urea and other waste products of the proteins, are dissolved solids and are removed from the blood to some extent by the intestine and the sweat glands of the skin, but chiefly by the kidneys.

A number of organs thus perform the work of excretion, but four of them — namely, the *lungs*, the *kidneys*, the *intestine*, and the *skin* — are of greater importance than all others. Of these four the lungs and kidneys are far more important than the intestine, and all three of these are more important than the skin.

2. Essential and incidental excretion by organs. An organ may be essential to the proper removal of a given waste, or it may remove the waste product only incidentally in performing its essential functions. Thus the skin removes a small amount of carbon dioxide from the body merely because a certain amount of this gas diffuses from the blood as it flows through the skin. It is not necessary to the health of the body that the skin should excrete this carbon dioxide, for the lungs are quite capable of doing the work and would do so if for any reason such excretion through the skin were prevented. Without the lungs, on the other hand, the carbon dioxide would rapidly accumulate in the blood and cause death. The lungs are essential to the removal of this waste; the skin is not. Similarly, the perspiration contains small amounts of urea and other wastes which are removed in large quantities by the kidneys. It is not necessary that the skin should remove any of these, for the healthy kidney can and does, when necessary, remove them. Small quantities of them appear in the perspiration because they are in the blood from which the perspiration is formed and because the cells of the sweat glands allow them to pass through, just as the skin allows the passage of carbon dioxide.

These considerations are of practical importance in the hygiene of the skin. It is not necessary to induce perspiration merely to remove waste products from the body. If the human skin, like that of the cat and the dog, contained no sweat glands, the waste products would be thoroughly removed; and in cold weather, when no perspiration is secreted, the excretion of waste is as complete as when in warm weather perspiration is abundantly secreted. On the other hand, perspiration, though not secreted to rid the body of wastes, nevertheless contains wastes which accumulate upon the skin. Hence the need of bathing, both as a matter of health and of decency.

The chief wastes leaving the body and their main channels of excretion are given in the following table, *incidental* excretions being given in *italics*:

Lungs: carbon dioxide, *water*.
Kidneys: urea, uric acid, and other compounds, salts, water.
Intestine: bile pigments, *nitrogenous compounds*, etc.
Skin: *urea*, etc., *salts*, *water*.

The structure and action of the lungs and intestine have already been described, so that we have left for study the kidneys and the skin.

3. Structure of the kidneys. Each kidney is a bean-shaped gland whose duct, the *ureter*, runs to the urinary *bladder*. As the ureter enters the kidney at the center of the depression in that organ it expands to form a basin, known as the *pelvis* of the ureter. Into this basin open the hundreds of glandular tubules of which the bulk of the kidney is composed. Each tubule, like the alveolus and ducts of the gland described in Chapter III, consists of a single layer of cells, which separate the blood and lymph from the lumen of the tubule; and *the formation of urine by the kidney is essentially an act of secretion.*

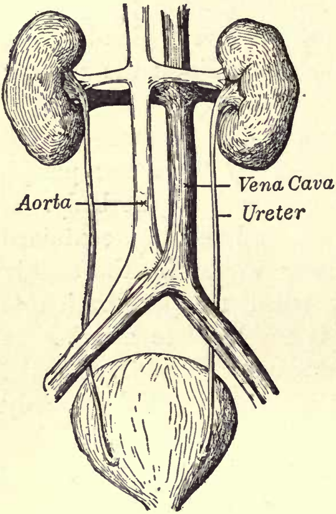


FIG. 81. Dorsal aspect of the kidneys, ureter, urinary bladder, and abdominal aorta and vena cava

4. The secretion of urine. The urine is secreted continuously from the blood, at one time more rapidly than at another, but under normal conditions never ceasing altogether. Passing down the tubules, it collects in the upper portion of the ureter, and successive peristaltic waves carry it from this point to the urinary bladder, an organ with muscular walls in which the urine accumulates and from which it is from time to time discharged.

In one very important respect, however, secretion by the kidney presents a sharp contrast to secretion by the stomach and the submaxillary gland. While an adequate blood supply to the two latter glands accompanies secretion and, indeed, is necessary to maintain the secretion for any length of time, yet these glands secrete only as they are stimulated to activity by their nerves; merely increasing their blood supply does not produce increased secretion. In the case of the kidney there seem to be no secretory nerves, and the activity of the gland seems *to be determined to a large extent by the* *quantity of blood flowing through it.* Anything which increases this quantity of blood increases the quantity of urine secreted; anything which diminishes it lessens the amount of urine secreted.

In the everyday experience of healthy people the activity of the kidneys is chiefly affected by three things; namely, (1) external temperature — more urine is secreted on a cold than on a warm day; (2) the quantity of water drunk; and (3) the quantity of food, and especially of protein food, eaten. All three of these agents, however, produce their results, largely if not entirely, because of their influence upon the blood flow through the kidney. Thus exposure of the skin to cold causes a constriction of the arterioles of the skin and a compensating dilation of those of internal organs, the kidneys included. More blood flows through the kidneys and more urine is secreted. Much the same thing is true of the absorption of water and of protein food, for both these conditions cause a widening of the arterioles of the kidney.

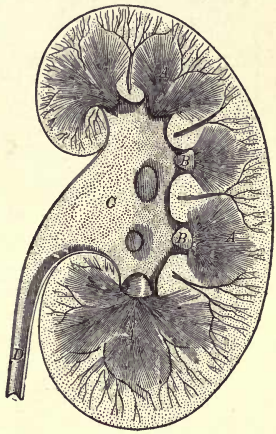


FIG. 82. Vertical section of the kidney. Diagrammatic

The tubules (*A*) of the gland open, on the papillæ (*B*, *B*), into the pelvis (*C*) of the ureter (*D*)

Changes in the quantity of the urine secreted are, generally speaking, only changes in the amount of water rather than in the amount of urea and other dissolved wastes. Certain constituents of the urine, however, are not very soluble, so that it is not well to have water, the only solvent of these substances in the urine, unduly diminished. A scanty secretion of urine during the day is, in general, a distinct indication, especially in warm weather, that insufficient water is being taken. Many persons drink too little water rather than too much.

5. The structure of the skin. The skin is an organ which performs several functions, the most important being (1) that of protecting the underlying structures from drying and mechanical injury; (2) that of assisting in maintaining the constant internal temperature of the body; and (3) that of receiving the external stimuli of pressure, heat, and cold. Incidentally, as we have seen, the skin is an organ of excretion. We may therefore describe its structure and excretory function in this connection, reserving the study of its other functions for Chapters XII and XIV.

FIG. 83. Cross section of skin

A, horny layer of epidermis; *B*, deeper layer of epidermis; *C*, duct of sweat gland; *D*, dermis; *E*, subcutaneous connective tissue (p. 7). The blood vessels are injected to show black. Cf. Fig. 89

The skin consists of an outer layer, the *epidermis*, and an inner layer, the *dermis*, *cutis*, or *corium*. The dermis consists of connective tissue richly supplied with blood vessels, lymphatics, and nerve fibers, together with sense organs of touch. The fiber bundles of the connective tissue are most dense near the epidermis; in the deeper portions the network is loose and the lymph spaces larger, the connective tissue of the dermis passing insensibly into that of the subcutaneous connective tissue.

The cells of the more open portions of the dermal network, and especially those of the subcutaneous tissue, store up more or less fat within their cytoplasm. The subcutaneous tissue, indeed, is one of the most important organs in the body for the storage of fat. Connective tissue in which large amounts of fat are stored is known as *adipose tissue* (see p. 223).

The outer surface of the dermis is not flat, but contains moundlike projections known as *papillæ*, which project into the overlying epidermis. Some of these papillæ contain nerve endings of the sense of touch, while others contain capillaries, which are found also in other portions of the dermis. The dermis is the vascular organ of the skin, blood vessels being entirely absent from the epidermis (see Figs. 86, 89).

The epidermis consists of many layers of cells, the number of layers being very great — a hundred or more on the palms of the hands and the soles of the feet; in other places less exposed to pressure or friction they may not exceed twenty. The deeper cells (that is, those nearer the dermis) are alive and in process of active growth and multiplication. The outer layers, which are further from the dermis with its blood supply and nearer the surface with its exposure to drying, degenerate and are gradually transformed into dead, flattened horny scales which, packed together, form the *horny layer*. These scales are being constantly rubbed off and their loss made good by the growth and multiplication of the living cells beneath. Such a covering or lining is well fitted for surfaces which are exposed to friction or drying, and we accordingly find that the mouth, the part of the pharynx used in swallowing, the œsophagus, and the rectum are lined with the same tissue. The endings of nerve fibers are found in the lower layers of the epidermis.

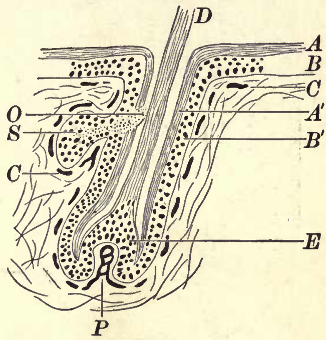


FIG. 84. Hair and hair follicle

A, horny layer of epidermis. *B*, layer of living, growing cells extending (*B′*) into the hair follicle, at the bottom of which it forms the mass of growing cells *E* over the papilla (*P*) with its knot of capillaries; the growth, multiplication, and transformation of these cells into horny fibers forms the shaft of the hair, *D*. *C*, capillaries in the dermis. *S*, a sebaceous gland discharging its oily secretion (*O*) into the follicle to lubricate the hair and the horny layer of the skin

The hairs, the sweat glands, and the nails are modified portions of the epidermis. Of these the hairs and the sweat glands are of sufficient importance to merit some description.

6. Structure of a hair and a hair follicle. A hair grows from the bottom of a pit, the hair follicle, which extends downward into the dermis or even into the subcutaneous tissue. Microscopic examination shows that this follicle is lined with a continuation of the epidermis, just as a gland of the stomach or intestine is lined by an ingrowth of the cells of its surface. At the bottom of the follicle is a papilla, and the hair which grows out from this papilla to the surface bears to the cells of the papilla the same relation that the horny layer of the epidermis bears to the similar underlying cells. We accordingly find that the hair is composed of horny scales closely pressed together into the well-known threadlike structure.

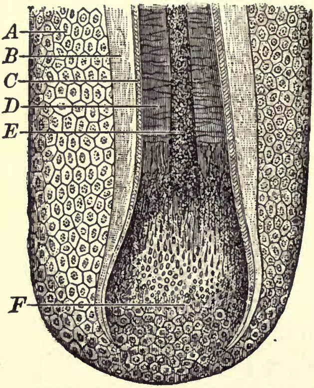


Fig. 85. Magnified section of the lower portion of a hair and hair follicle

A, membrane of the hair follicle, cells with nuclei and pigmentary granules; *B*, external lining of the root sheath; *C*, internal lining of the root sheath; *D*, cortical or fibrous portion of the hair shaft; *E*, medullary portion (pith) of shaft; *F*, hair bulb, showing its development from cells from *A*

Opening into the hair follicle, one or more *sebaceous glands* discharge an oily secretion which lubricates the hair and the horny layer of the epidermis, and so prevents drying and chapping (Figs. 84 and 85).

7. The sweat glands are tubular prolongations of the epidermis through the dermis into the subcutaneous tissue. Here the tube becomes much coiled, forming the secreting recess, which is richly supplied with blood vessels and also receives nerves. It is a simple tubular gland formed as an ingrowth from the epidermis (see Figs. 86 and 89).

8. The secretion of the perspiration, like the secretion of the gastric juice, is under the control of the nervous system. When the nerves going to the sweat glands of a given area of skin are cut or otherwise injured, the secretion of perspiration ceases over that area; and the appearance of cold beads of perspiration as the result of fright shows how events taking place in the nervous system may excite these glands to activity apart from the presence of their usual stimuli — the application of heat to the skin and the liberation of heat within the body by muscular and other activities. The distinction should be made between the so-called "sensible" and "insensible" perspiration, the latter name being given to the perspiration the water of which evaporates as fast as secreted; the former to that which does not evaporate so rapidly and hence remains for a time on the surface of the skin. When the water evaporates, the dissolved solids (salts, urea, and other compounds) remain behind on the skin.

FIG. 86. Sweat gland (slightly magnified)

Note the coiled form of the tube in the subcutaneous tissue. Cf. Fig. 89

9. Value of profuse perspiration in the care of the skin. While the skin is not primarily an organ of excretion, the perspiration contains a certain amount of waste substances and salts, which are left by the evaporation of the water upon the surface and, to some extent, in the mouths of the ducts of the sweat glands; this is especially the case when evaporation takes place about as rapidly as the perspiration is discharged. When the secretion of perspiration is more abundant, as during muscular work, or at very high temperatures, or, in general, where it does not evaporate as rapidly as discharged, the accumulation of solids in the ducts of the glands is washed out. For this reason a vigorous perspiration followed by a bath is a useful hygienic measure in the care of the skin, although it is not necessary, as is sometimes supposed, in order to secure the efficient elimination of wastes from the blood.

10. The skin as an organ of absorption. While it is true that water as perspiration may readily find its way out through the skin, such escape is effected chiefly by the sweat glands, which are under the strict control of the nervous system. Apart from this the skin is virtually watertight; and, oiled as it is by the secretion of the sebaceous glands, it serves both to keep in the water, which forms so important a part of the tissues, and also to keep out water which might otherwise soak into the body, as, for example, during bathing. This waterproof characteristic also makes it next to impossible for us to absorb food materials by way of the skin. A "milk bath" may be at times useful in the care of the skin, because the fat or oil of the milk may supply any deficiency in the sebaceous secretion and so insure lubrication of the epidermis; but it cannot be regarded as a means of supplying food to the body.

CHAPTER XII

THERMAL PHENOMENA OF THE BODY

A. The Constant Temperature

1. The normal temperature. No characteristic of the human mechanism is more remarkable than its constant temperature. Whether we are awake or asleep, by night or by day, at work or at rest, at home or abroad, in summer or in winter, in the tropics or in the polar regions, in subterranean caves or on lofty mountain peaks, the temperature of healthy human beings is always nearly the same. So steady is this temperature that an increase or decrease of two or three degrees gives just cause for anxiety, and a change of seven or eight degrees is looked upon with alarm.

In many modern laboratories constant temperatures are obtained by the use of a *thermostat*, the apparatus of which is visible and easily understood; but no such special apparatus regulates the constant temperature of the human body, and we have rather to seek an explanation in the coördinated activities of organs already familiar, such as muscles, skin, blood vessels, and especially the all-controlling nervous system.

2. Temperature and chemical changes. Every chemical reaction takes place more readily under some external physical conditions than under others, and among these conditions none is more important than temperature. This fact is illustrated in the case of the enzymes. At the freezing point saliva exerts no action upon starch paste; as the temperature rises, the activity of the enzyme increases up to a certain point and then diminishes more or less rapidly until a point is finally reached at which its peculiar chemical properties are destroyed.

3. Temperature and vital activities. When we come to the activities of living cells — activities which, it will be recalled, depend on chemical changes — precisely the same thing holds true and in so striking a manner as to create a widespread but erroneous impression that this dependence upon temperature is peculiarly characteristic of living things. The one-celled animal, amœba, moves about more actively and digests more food at 20° C. than at 10° C.; bacteria grow more rapidly at the room temperature than near the freezing point; the pitch of the note made by a cricket rises with the temperature, indicating that the movements of the wing covers which produce the sound are being made more rapidly; and in the winter sleep of hibernating animals we have a beautiful example of the decline of vital activities with the fall of external temperature.

Nor are the living cells of the human body exceptions to this rule. The rate of the heart beat varies directly with the temperature of the blood, and the character of the breathing movements is influenced by the same cause; a cooled muscle contracts more slowly, a cooled gland secretes less abundantly. If the temperature of the body itself falls, every vital activity is depressed, and death itself may result from undue cooling.

4. The constant temperature of the body. This depression of nervous, muscular, and glandular activity results, however, only from a fall of the temperature *of the body*, not of that of the surrounding air or other medium. These two things are by no means the same, as may be readily seen from the fact that a thermometer placed in the mouth indicates almost the same temperature of the body on warm and on cold days; even while we are shivering with cold the thermometer gives about the same reading as when we are enjoying the warmest summer weather. The temperature of the body remains nearly constant, regardless of changes in the temperature of the air around it.

We have only to appeal to experience to see that this is not the way in which lifeless matter generally behaves; a stone, the earth, a piece of iron is warmer on a warm day and colder on a cold day; in general, lifeless things take the temperature of the medium in which they are placed, and this is one of the fundamental principles of physics. Nor do most living things act differently; the temperature of a plant or a tree, of an earthworm, a frog, a turtle, a snake, does not differ greatly from that of its surroundings. It is *only birds and mammals* which show this remarkable power of maintaining an approximately constant body temperature notwithstanding wide limits of change in that of the surrounding air. Such animals are known as *warm-blooded* because they are usually warmer than surrounding objects; those animals which do not thus maintain a constant temperature, on the other hand, are known as *cold-blooded*.[1]

It is clear that the power to maintain a constant body temperature is of the utmost importance in enabling an animal to counteract the varying conditions of climate. Were it not for this power, man would be a hibernating animal; with the coming of winter all his activities would gradually be slowed down and, long before our rivers and ponds had begun to freeze, all business, industrial life, and intellectual life would come to a standstill; it would not be possible for the human race to people every zone of the earth — the shores of Alaska or Iceland as well as the banks of the Ganges or the Amazon.

5. The temperature of the body not absolutely constant. The term "constant" as applied to the temperature of

[1] A cold-blooded animal exposed to a temperature of 99° F. is as warm as a warm-blooded animal. Such animals are so called because they usually feel colder when handled than do warm-blooded animals; but this is merely because the temperature of the air (which is also their temperature) is usually lower than the temperature of warm-blooded animals.

warm-blooded animals is not, however, to be taken too literally. No animal has an absolutely constant temperature. In the first place, there are slight variations from time to time under the changing conditions of life. The temperature is higher by from one to four degrees during muscular activity than during rest; it varies during the day, being highest in the afternoon and lowest in the small hours of the morning; it is often raised half a degree or more by taking food, and marked changes of surrounding temperature may cause a change of one degree or even more in that of the body. These changes between 97.5° and 99.5° F. are of everyday occurrence and are entirely normal; so that when we speak of the temperature of the body being constant we mean that it varies only within narrow limits or that it is constant in comparison with that observed in cold-blooded animals.

6. The temperature of different organs. Nor is this all; some parts of the body have a higher temperature than others. Thus the temperature of the liver is often as high as 107° F.; that of the muscles varies between 99° and 105° F.; that of the blood in the right side of the heart is usually a degree or so higher than that of the blood in the left side. But it is in the skin that we meet with the widest variations from the general average. Everyone knows that on a very cold day the temperature of the skin may be far below 98.6° F.; indeed, the experience of "frosted" ears or feet shows that at times cutaneous temperature may descend to, or even below, the freezing point itself; and it is very exceptional indeed when the skin temperature is above 92° or 93° F., even on very hot summer days. These variations are due to the fact that the skin is the organ which is immediately exposed to the changing environment and hence peculiarly subject to cooling influences. It is therefore customary to distinguish between an outer body zone of variable temperature and the more constant temperature of internal organs.

7. Measurement of the body temperature. The great equalizer of the body temperature is the blood. Blood which has flowed through the skin comes away cooled; that which comes from an organ like the liver or a working muscle, in which active oxidations or other chemical changes have taken place, is heated. In the great veins and in the heart the warmer blood is mixed with the cooler, and an average temperature of the arterial blood results. It is this average temperature of the arterial blood flowing to the organs that is approximately constant.

When this blood flows for a time through an organ which is itself not producing heat and is at the same time protected from loss of heat, the organ ultimately takes on the temperature of the blood; so that by measuring the temperature of such an organ we get the temperature of the blood itself. It is customary to take the temperature in the mouth, the bulb of the thermometer being placed under the tongue and the lips kept closed. Subject to the variations mentioned above, the temperature of the mouth is 98.6 F.

8. The feeling of cold or warmth not a true test of the body temperature. It is well at this point to warn the student against confusing the body temperature with sensations of cold or warmth. Just as visual sensations are aroused only by that light which falls upon the sense organ especially adapted to respond to its stimulation, namely the eye, while light falling upon the skin arouses no such sensation, so heat and cold can excite the corresponding sensations only when they act on special end organs adapted to receive these stimuli, and these end organs are found only in the skin, the mouth, and perhaps the nose, pharynx, and upper œsophagus. We are therefore conscious only of the temperature of these organs; we are not and cannot be conscious of the temperature of the blood or of internal organs generally. It is therefore clear that our feelings give us no reliable information as to the temperature of the internal parts of the body. This fact is strikingly illustrated in the case of a "chill," when the internal temperature is almost always really above, and not below, the normal, and the feeling of warmth produced by muscular activity or by warming one's self at a fire merely indicates a higher temperature of the skin, not a higher temperature of internal organs.

Having now learned the more obvious facts about the constant temperature of the body, we have next to inquire by what means this constant temperature is maintained.

9. The production and the loss of heat. We must first remember that *the body produces* or *liberates heat.* The chemical changes, largely oxidative in character, which are at the basis of the work of its muscles, glands, nerve cells, etc., liberate heat just as truly as the burning of coal in the furnace of an engine liberates heat. Heat production is therefore an indispensable result of cellular and organic activity, and it is greatest in those organs, like the muscles and liver, which carry out the most active chemical processes. The body is warm for the same reason that a stove is warm; that is, because heat-producing chemical changes, largely of an oxidative character, are going on within it. In the second place, *the body is always losing heat*, and this in two ways: (1) by the *transfer of heat* by conduction, convection, and radiation [1] to colder objects or to the colder air with which the body is surrounded, and (2) by the *evaporation* of water from the surfaces of the body — especially by the evaporation of water of perspiration.

Everyone knows in a general way that when a warm body is brought near a colder one, the former becomes colder and the latter warmer; heat is transferred from the warmer body to the colder. In this way the clothing is warmed by

[1] Those not familiar with the meaning of the terms "conduction," "convection," and "radiation" will find them explained in section 26 of this chapter (p. 211). In the following discussion we have arbitrarily adopted the term "heat transfer" to include these three means of heat loss, in order to distinguish them from the loss of heat by evaporation.

contact with the body; so is the air in immediate contact with the skin; and conversely the body may be warmed by contact with anything warmer than itself, a hot-water bottle, for example. It is not, however, necessary that two solid bodies be in actual contact in order that heat may pass from one to the other. A stove warms all the objects in a room, although few of them are touching it; and the human body may lose heat to, or gain heat from, objects at a greater or less distance. The heating of the body by the sun, millions of miles away, clearly shows this fact.

The loss of heat by evaporation of water or other liquid from the skin may be readily illustrated by the simple experiment of blowing a gentle current of cool, dry air over the *dry* hand and comparing the cooling thus produced with that which results from blowing a similar current against the *moistened* hand. In the latter case the cooling will be much greater than in the former. Liquids, like ether, which evaporate more rapidly than water will produce even greater feeling of cold on the skin.

10. The heat account of the body. The body is therefore constantly receiving and constantly giving out heat, just as a bank is constantly receiving and paying out cash. In the bank a cash account is kept, on one side of which is entered the cash received and on the other the cash paid out. The difference between the two sides, known in business as the *balance* of the account, shows how much cash is on hand at the time of taking the balance. Should the cash unduly accumulate, efforts are made to keep down the balance by increasing loans; should the cash on hand fall below a desired level, active efforts to encourage loans are lessened and the normal desired balance is restored; finally, should there be an unusual demand for cash at the window of the paying teller, for example, a "run on the bank," the bank will borrow from other banks and in this way keep income and outgo of cash approximately equal.

In what follows the student will learn that this is precisely what the body is doing with regard to heat. We may, indeed, imagine a heat account of the body, the two sides of which would be as follows:

Debit (Heat received)	Credit (Output of heat)
1. Heat produced within the body.	1. Heat transferred to surrounding objects colder than the body (by conduction, convection, and radiation).
2. Heat transferred to the body from warmer objects without (by conduction, convection, and radiation).	2. Heat lost in evaporating water of perspiration, etc.

The balance of this heat account at any one time is the amount of heat in the body, and this determines the temperature of the body. When the output of heat exactly equals the heat received, the balance of the account remains the same; that is to say, the temperature is constant. A constant temperature, therefore, means that the two sides of the heat account are being kept equal to each other. If the balance increases, either by the production of more heat or by the loss of less, the temperature of the body rises, and we have fever.

11. Transfer of heat dependent upon the nature of the vehicle of transfer. The rate at which heat may be transferred depends upon the nature of the substance through which the transfer occurs and which we may speak of as the vehicle of transfer. We cannot go minutely into the factors here concerned, but would call attention to the following points, which will be readily verified from experience:

1. *A gas is in general a poorer vehicle of heat transfer than a liquid or a solid.* We make use of this fact in the manufacture of fabrics for our warmer clothing, for these fabrics are warm according to the quantity of air within their meshes. A woolen garment is warmer than a cotton garment because it contains within the fabric so large a quantity of the poorly

conducting air; or, of two woolen garments of the same thickness, one of which is rather loosely and the other tightly woven, the loosely woven garment will be much the warmer because so large a proportion of its thickness consists of the poorly conducting air rather than of the rather rapidly conducting solid woolen fibers (see p. 423). Or, again, air of 70° F. is very comfortable; it feels neither cold nor warm to the skin; but water of 70° F. feels distinctly cool. This is because heat is conducted away from the skin more rapidly by water than by air. For this reason we may feel chilly when our clothing has become drenched with rain.

2. *Moist air is a better vehicle of heat transfer than dry air.* This becomes obvious when one is exposed to damp air at a temperature of less than 70°, and the familiar difference between dry and damp winds in winter illustrates the same fact, for a damp wind at 50° F. chills the skin more than a dry wind at 40° F. The student is cautioned, however, against supposing that dampness always favors the output of heat from the body; it favors only one method of heat output, namely the *transfer* of heat. On the other hand, dampness hinders the output of heat by evaporation. Hence at those temperatures (above 80°) where the output is chiefly by evaporation, a damp atmosphere is close, warm, and muggy; where the output is chiefly by heat transfer (below 70°), a damp atmosphere is chilly.

12. The evaporation and not the secretion of perspiration cools the body. The student should understand clearly that it is the evaporation of the perspiration, not the secretion of it, which abstracts heat from the body. Perspiration may be *secreted* in large quantities, but if it does not evaporate, — as happens on a very moist, humid, muggy day, when the atmosphere already contains about as much aqueous vapor as it can hold, — it takes little or no heat from the skin. Nor is the efficiency of the perspiration as a cooling agent measured by the amount of visible or "sensible" perspiration, for this is only the perspiration which has not evaporated; the true measure of the cooling effect would be the perspiration which has evaporated and of which we are not conscious.

It is important to note that the evaporation of perspiration (or of water from the lungs and air passages) is the only means of cooling the body when objects around it are warmer than the body itself. In this case the agents of heat transfer only add heat to the body, but even their combined action may often be overcome by an abundant evaporation of perspiration. Men have remained for some time in rooms whose temperature was as high as 260° F., or 48° above the boiling point of water, without any marked rise of the body temperature and without severe discomfort, the temperature of the body being kept down solely by the evaporation of perspiration from the skin. In order to make this means of cooling possible, it is absolutely essential that the air be dry and capable of taking up moisture. No one can survive long at such temperatures in moist air.

13. The effect of stagnant versus moving air; the aërial blanket. On a perfectly still day the layer of air about the body becomes warmed by the skin and, so long as it is not removed, forms an air-blanket which goes far to keep the skin warm; for air is a poor conductor of heat. As soon, however, as a breeze springs up, convection comes into play and the skin is cooled more rapidly. In stagnant air, moreover, the evaporation of the perspiration tends to saturate this air-blanket with water vapor, so that further evaporation is rendered difficult. Accordingly, when perspiration is not being secreted, moving air cools the body by increasing convection; and when the skin is moist it cools the body both by increasing convection and by facilitating the evaporation of perspiration. The breeze which in winter is an unwholesome draft, in summer is often absolutely essential to working power as well as to bodily comfort, for without it we are clothed in this aërial blanket.

B. The Regulation of the Body Temperature

14. How the balance of the heat account may be disturbed. Events both within the body and in its immediate surroundings tend to change the balance of the heat account; that is, to upset the equilibrium previously existing between heat loss and heat production. The most important of these events are (1) muscular activity and the digestion of food within, and (2) changes of atmospheric or weather conditions without. Let us consider how each of these acts.

Muscular activity, by producing more heat within the body, would tend to increase the heat balance; and, unless measures were taken at the same time to increase heat output, the temperature of the body would rise. Muscular activity may double or even treble the heat produced. The *digestion of a meal* similarly liberates heat within the body and so tends to raise its temperature, but the heat produced in this case is far less in amount than that produced during muscular activity.

Changes of atmospheric or weather conditions act by changing the ease with which heat is lost; and, remembering that heat is lost in two ways,—by transfer to colder surroundings and by evaporation of perspiration,—we must inquire how various weather conditions influence each of these agents of heat output. The three main weather conditions are the *temperature*, *movement*, and *moisture* of the air, and the following tabular form will aid in understanding the relation of each of these conditions to the heat output of the body.

I. TEMPERATURE OF AIR

A. Influence on Heat Transfer	*B.* Influence on Evaporation
Heat is transferred more rapidly to colder surroundings than to surroundings which are near the temperature of the body.	The warmer the air, the more water vapor it can take up. This facilitates the evaporation of perspiration on a warm day, when this is most needed to cool the body.

II. MOVEMENT OF AIR

A. Influence on Heat Transfer

Movement of air increases heat transfer to the atmosphere by replacing the "aërial blanket" of warmed air with colder air, to which heat is transferred more rapidly.

B. Influence on Evaporation

When perspiration is evaporating into stagnant air in contact with the skin, this air becomes more nearly saturated with water vapor, and its power of absorbing water vapor is lessened. By replacing the "aërial blanket" of muggy air with dry air, the output of heat by evaporation is greatly favored.

III. HUMIDITY OF THE ATMOSPHERE

A. Influence on Heat Transfer

Humidity increases the rate of transfer of heat, as explained on page 197. This is of little importance on warm days, because little heat is then transferred either by dry or by moist air. On cooler days it is of great importance.

B. Influence on Evaporation

Humidity diminishes the output of heat by evaporation, because the water vapor which the atmosphere can take up is limited and a humid atmosphere is one already largely saturated. This influence of humidity is of no consequence unless perspiration is being secreted, but it is a very important matter on warm days.

15. How the heat balance when disturbed is restored by the body. In these ways changes in the activities of daily life and changes of weather tend to change the heat balance of the body — that is to say, they tend to change the temperature of the body. And they would do this, did not the body possess the power, within certain limits, of changing both its rate of heat loss and its rate of heat production.

The rate of heat loss may be changed in two ways: (1) by changing the quantity of blood flowing through the skin. Obviously the more the warmed blood is kept within the internal organs, the smaller will be the amount of heat transferred from the surface of the body to surrounding objects. The student now understands the reason for the reactions of the circulation to changes of surrounding temperature. The entire vasomotor mechanism with its vasoconstrictor and vasodilator nerves thus forms part of the mechanism of temperature regulation. The rate of heat loss may also be changed (2) by producing a secretion of perspiration. This secretion begins at about 68° or 70° F. in the body at rest and increases in amount as the external temperature rises. The sweat glands are thrown into action by nervous impulses. Hence the nervous system through its nerves to the arterioles and the sweat glands controls the output of heat from the body.

The nervous system also controls the rate of heat production, for this is changed by increasing or diminishing the activity of the skeletal muscles. We are more active on cold than on warm days, and this apart from any conscious adjustment of muscular activity to the temperature needs of the body. We shall return to several interesting features of this part of our subject in later paragraphs.

16. Reactions of the body at rest and lightly clad to changes of external temperature. Having learned the more important principles concerned in maintaining the constant heat balance, let us now observe the actual behavior of the body as the external temperature changes, assuming that the air remains of moderate humidity and that there is little or no wind.[1] To do this let us suppose that the body at rest and lightly clad is exposed, to begin with, to a temperature of 90° F. At this point but little heat is transferred by conduction, convection, and radiation from the skin to surrounding objects, since both are so nearly of the same temperature. Hence the main reliance for getting rid of the heat constantly being liberated is upon the evaporation of the perspiration, which

[1] Consult Fig. 87 when reading this section.

is abundantly secreted; the cutaneous arterioles are also widely dilated. Let us now suppose the day becomes cooler and the temperature falls to 80° F. Heat production remains unchanged; but more heat is now transferred to the cooler surrounding objects, and less is lost by evaporation because less perspiration is secreted. As the external temperature falls further, still more heat is transferred to colder objects

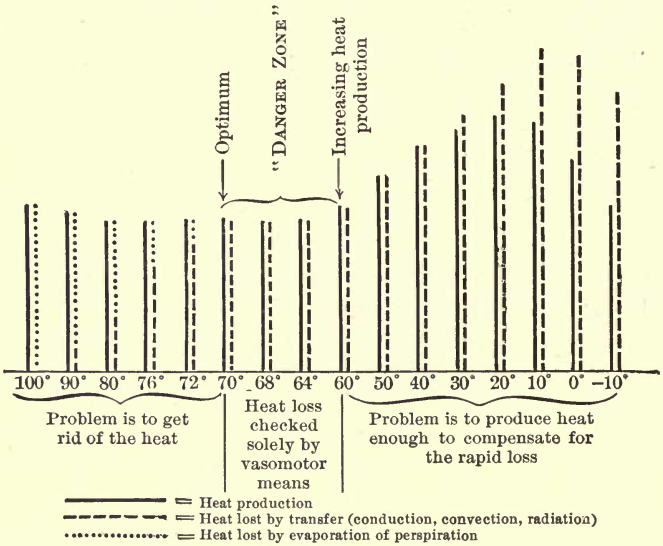


FIG. 87. Production and output of heat at different temperatures

and correspondingly less is lost by evaporation of the perspiration until, somewhere about 68° to 70° F., exactly the same amount of heat is lost by conduction, convection, and radiation as is produced. *At this point the secretion of the perspiration ceases.*

Thus far the difficulty in maintaining a constant temperature has been that of getting rid of heat under atmospheric conditions which are unfavorable for the ready conduction, convection, and radiation of heat from the skin. Blood is brought in large quantities to the skin and correspondingly drawn away from internal organs, and the evaporation of perspiration becomes increasingly important as the external temperature rises from 70° F. to 90° and 100° F. *The organism is striving against a rise of its body temperature.*

About 68° or 70° F., however, the situation changes; for, as the external temperature continues to fall, heat begins to be transferred to surrounding objects more rapidly than it is produced. The temperature of the body would fall if no means were taken to prevent the result. Even during the fall from 90° to 70° the cutaneous arterioles, widely dilated at the higher temperature, have been gradually increasing their tone and so sending diminishing quantities of blood through the skin. *Below 68° to 70° this tone rapidly increases;* the veins are no longer conspicuous on the hand and arm; if the blood is forced out of a portion of the skin by gentle compression with the finger, the color returns slowly, indicating considerable constriction of the cutaneous arterioles. At the same time the arterioles of internal organs are dilating (see p. 152) so that the liver, the kidneys, the mucous membranes of the alimentary canal and of the air passages contain an increasing quantity of blood. *The body is now striving against a fall of its internal temperature by driving the blood from the skin back upon internal organs.*

By the time the temperature has fallen to 60° F., or thereabouts, the cutaneous arterioles have constricted to their utmost, the blood flow through the skin has nearly ceased, and the organism has no means at command by which to restrict the further output of heat. If in this emergency heat production were to remain constant while external temperature continued to fall, the temperature of the body would be lowered, for the transfer of heat would not only continue but increase. That it is not usually lowered is due solely to the fact that more heat is then produced within the body; the oxidations (and hence heat production) which have remained fairly constant in amount between 90° F. and 65° F. now increase to compensate the inevitable loss, and continue to increase as the atmospheric temperature continues to fall. *The body is now striving against the effects of a rapid and inevitable loss of heat by producing more heat*, and continues to do so until somewhere near the freezing point (32° F.) it can no longer produce enough heat to balance the loss; the temperature of the body then falls and the man ultimately freezes to death.[1]

Briefly, then, at an external temperature somewhere between 65° and 70° heat production exactly equals heat transfer, and it is not necessary that the body make any special effort to get rid of heat or to compensate for heat loss. *The blood is properly distributed between the skin and internal organs, and there is no excess in either.* This we may call the *ideal* or *optimum* temperature, for the given conditions. Above this point measures must be taken to provide for an adequate heat output by sending a larger quantity of blood to the skin and by the secretion of perspiration; below this point measures of the opposite kind must be taken to check heat loss or even to increase heat production.

17. Changes of the optimum temperature with high humidity, with wind, and with muscular activity. High humidity, by facilitating the transfer of heat from the body, raises the optimum temperature a few degrees; a room is comfortable at 65° when the air is dry; it is too cool when the air is moist. Wind may raise the optimum temperature still more, and for the same reason; it may be safe to sit in a breeze at 75° when it is decidedly unsafe to do so at 65° or 70°.

Muscular activity on the other hand, because of the production of larger quantities of heat, lowers the optimum temperature, for at the lower temperature the agencies of heat transfer can get rid of the excess of heat without a large blood flow to the skin and without inducing perspiration.

[1] In all this it must be remembered that the body is still lightly clad and at rest.

In all cases, — rest or muscular activity, high or low humidity, wind or calm, — wherever the point of optimum external temperature may be, we always find above this point the region of active measures for heat dissipation, and below it the region of active heat production. This is graphically shown in Fig. 88.

18. The "danger zone" of atmospheric temperature. We have seen that, as the temperature falls from 70° to 60°, the main agency employed for temperature regulation is the diminution of the blood flow through the skin, with its compensating increase of *the blood flow within internal organs*, thereby retaining

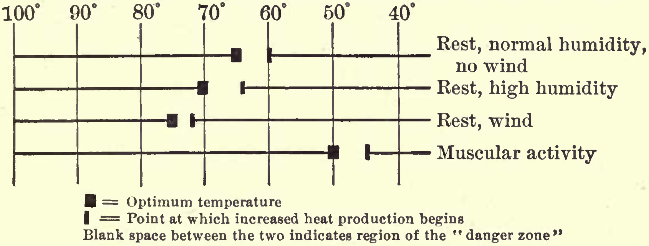


FIG. 88. Variations in the optimum temperature

as far as possible the heat within the body. This threatens serious congestions and other unhealthful conditions, which we shall consider at length in our study of hygiene (see Chap. XXI). It is because the temperature of a room may fall from 66° to 60° so gradually that we do not notice it until the internal damage is done, whereas it could not fall to 50° or 40° without our noticing it and correcting the trouble, that more colds are taken in the former case than in the latter. In other words, as the temperature goes below 65° the body seems at first to rely wholly on the vascular mechanism of temperature regulation, and does not begin to produce more heat until this resource has been utilized not only to its utmost, but even to an extent inconsistent with health. The "danger zone" temperature may then be defined as beginning a degree or two below the ideal or optimum temperature and extending about five degrees below this point. Like the optimum temperature, its exact position varies with atmospheric conditions and with the amount of muscular activity.

19. The influence of clothing. In the discussion above we have assumed that the clothing has not been changed with the change of external temperature, etc. Clothing, however, may modify greatly the figures given above, for it interferes with the loss of heat from the skin, and the obvious effect of increasing its weight is to lower the optimum temperature and the region of dangerous temperature. By changes of clothing, by muscular activity, and by the use of fans, man has it in his power to supplement the unconscious reflex adjustments which we have thus far been studying by a conscious adaptation to changing conditions of climate or weather. The hygienic use of clothing will be discussed in Chapter XXVI.

20. Temperature regulation and muscular activity. The reactions of the body to maintain its constant temperature during muscular activity are familiar to everyone, and it is only necessary to sum them up and to point out some practical applications. The arterioles of the skin are dilated (while those of internal organs are constricted) and perspiration is secreted. These are the same reactions which are noticed when the body is exposed to external warmth, and their purpose is the same in both cases — to facilitate the escape of heat. But in the one case they are made necessary by the fact that climatic conditions interfere with the output of heat, in the other by the fact that more heat is being liberated and hence more must be got rid of.

Seldom indeed is so severe a strain imposed upon the mechanism of heat dissipation as during vigorous muscular exertion, and especially when the external conditions are not favorable for the output of heat. Caution is then urgently indicated lest we make the strain too great. It is a practical point to remember in this connection that some forms of muscular exertion introduce conditions for getting rid of the surplus heat much more readily than others; this is especially true of those which involve movement of the body as a whole. Bicycle or horseback riding, by creating a breeze, renders the cooling of the body a much easier matter than does sawing wood, or swinging Indian clubs, or gymnastic work in general; again, a particular form of exercise on a dry day, when the perspiration can evaporate readily, may be safe, while it would be decidedly inadvisable on a muggy day, even though the temperature were somewhat lower. Indeed, by this time the student must have learned that the thermometer alone is no safe indicator of the difficulty of heat elimination in warm weather.

21. Relations of climatic conditions to mental work and sleep. During mental work the brain requires an increased supply of blood, and this is obtained partly by diminishing the supply to the skin (constriction of cutaneous arteries); during sleep, on the other hand, the supply to the brain is diminished, and this is ordinarily effected by dilating the arteries of the skin (see p. 155). Mental work is difficult on very warm days, partly because it is difficult to bring about cutaneous constriction; and it is especially difficult on warm, muggy days, since the maintenance of the constant temperature then requires an excessive cutaneous dilation, and the brain is quite unable to command its needed blood supply.

It is also clear that since the arterioles of the skin should dilate during sleep, and since they cannot readily do this when the skin is exposed to cold, to "sleep warm" is good advice, based on sound physiological principles.

22. Digestion and the maintenance of the constant temperature. During digestion, and especially during its earlier stages, when secretion is at its maximum, a large supply of blood is needed in the stomach, the pancreas, and the intestine. This cannot readily be secured when blood is being sent in large quantities to the skin in order to cool the body. We have seen all along that the two great vascular areas of the skin and digestive organs are more or less antagonistic or compensating in their vasomotor reactions. When the blood is present in large quantities in the skin, it is present in smaller quantities in the stomach, the intestine, the pancreas, the liver; and, vice versa, these organs can best obtain an adequate blood supply when the demands of the skin are not excessive. Consequently digestion is more difficult in warm than in cold weather, and we should then eat less at a time, even if we have to eat somewhat more frequently.

During the digestion of a meal the chemical activities of secretion, the peristaltic muscular movements, etc., somewhat increase heat production in the body; and this increase, though not great, is at times great enough to make us feel distinctly warmer. When one is *slightly* chilly, for example, he often feels warmer after eating something, even though the meal be cold; and on a very warm, muggy day, when the blood flow through the skin is already excessive and its temperature unduly high, the digestion of a meal often adds to the discomfort, because the larger production of heat leads to further dilation of the skin vessels.

23. The mechanism of temperature regulation. The preceding pages have shown us that temperature regulation depends chiefly on three physiological mechanisms: (1) the vasomotor system, which controls the distribution of blood between the skin and the internal organs; (2) the sweat glands; (3) the mechanism of heat production. The first of these has already been described in the study of the circulation. The heating of the skin stimulates afferent nerves which reflexly dilate the arteries of the skin and also simultaneously constrict those of internal organs. This reflex, then, is dependent on the temperature of the skin;

anything which heats the skin causes a reflex dilation of its arterioles and lessens the supply of blood to internal organs.

The secretion of perspiration is also under the control of the nervous system. The sweat glands, like the salivary glands, receive nerves, and secrete only in response to their stimulation. When the nerves going to the sweat glands of any region are injured, exposure of these glands to external

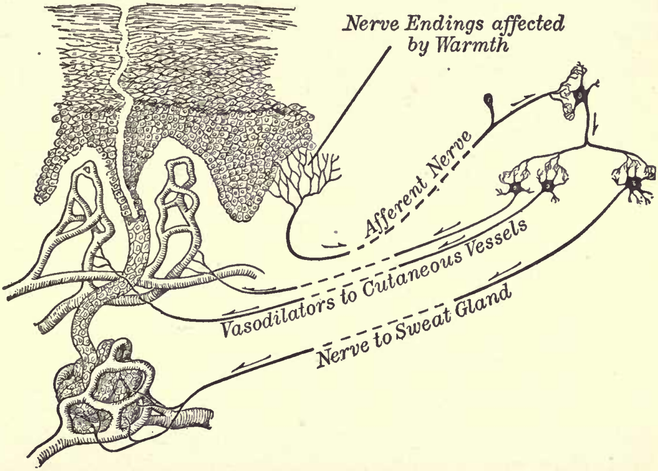


FIG. 89. Diagram of the cutaneous reflexes of temperature regulation
Showing the epidermis, blood vessels of the dermis, a sweat gland, and the nervous mechanism governing blood vessels and sweat glands

warmth produces no perspiration; stimulation of their nerves, however, produces a copious secretion.

24. The skeletal muscles the main organs in the regulation of heat production. The third mechanism of heat regulation is that whereby the amount of heat produced is increased as it is needed. The main organs here concerned are the skeletal muscles. As the afferent impulses started in the skin by the stimulation of cold become stronger, they ultimately stimulate reflexly the skeletal muscles to contraction, and so to the production of heat. This contraction does not ordinarily produce motion, because antagonistic muscles are stimulated equally; but in another way we are often conscious of this increased muscular action. Everyone knows the difference between the "bracing" effects of a cool or cold day and the "relaxed," "slack-twisted" feeling on a warm day; and this is largely traceable to the sensations which come from the contracting muscles in the former case and to the absence of such sensations from the inactive muscles in the latter. To put it in another way, cold increases the *tone of the skeletal muscles* (see p. 161). A skeletal muscle on a cold day is never completely relaxed; like the unstriped muscles of the arteries, it is in a condition somewhere between extreme contraction and extreme relaxation.

This muscular reflex also betrays itself in *shivering.* Ordinarily the reflex contraction consists of an even, steady tone, but at times it becomes more or less incoördinated, and shivering results.

25. The regulation of the body temperature a function of the nervous system. We may close this brief account of thermal phenomena of the body by recalling to the attention of the student what must now be obvious at a glance; namely, that a constant temperature is maintained by the coördinating action of very many nervous reflexes. The action of the vasomotors of the skin and of the internal organs, of the nerves of the sweat glands and of the motor nerves of the skeletal muscles must all be so adjusted with regard to one another that exactly the right balance is preserved amid all the variations of heat production and of climatic conditions which affect heat loss. Success in this adjustment depends upon the skill with which the coördinating nervous system does its part. With the single exception of muscular exertion, no condition of life makes such far-reaching or such imperious demands upon the system as a whole as does the maintenance of the proper internal temperature. Mental work and the efficiency of digestion are examples we have already studied — and more could easily be cited — of functions which, important as they are, are subordinated, even sacrificed, to prevent a marked rise or fall in the temperature of the blood.

To such an extent is the nervous system as a whole adapted to maintain the constant temperature, that the failure to do this, as shown by the presence of fever or by the even more serious subnormal temperature, becomes one of the most important indications that something has gone wrong. We know already how the nervous system intervenes in every function of our lives, and how the well-being of the body as a whole depends upon the adjustments which it brings about. It is for these reasons that, when it is no longer able to exercise that firm control of the constant temperature which is one of its most characteristic features in health, the physician's orders usually are to "go to bed and be perfectly quiet." The body is then in no condition to make demands on the nervous system for action; and a person who refuses to heed the plain warning which his temperature holds out has nothing but his own foolishness to blame if he suffers serious consequences.

26. Definitions. Those not familiar with the exact meaning of the terms "conduction," "convection," and "radiation" will find the following helpful.

Conduction. Whenever heat is transferred directly from one mass of matter to another with which it is in *contact*, such transfer is known as conduction. A good example is the heating of a poker in a fire; the heat of burning coal is communicated directly to the outer particles of iron and then from one particle of the iron to another. The particles of iron do not move up and down the length of the poker; each one simply passes on to the next the heat it has received, and finally those of the handle communicate their heat to the hand. All transfer of heat *along solid objects*, or from one mass of matter to another with which it is in immediate contact, is by means of conduction.

Solids and liquids are much better conductors of heat than gases, and air when perfectly still is one of the poorest conductors of heat with which we have to deal. It is a familiar fact that the skin is chilled much more rapidly by water than by air of the same temperature (why?); and we shall learn in hygiene that warm fabrics owe their warmth mainly to the amount of poor-conducting air stagnant within their meshes.

Convection. When a warm body is surrounded by a fluid such as water or air, heat is similarly conducted to the adjacent layer of water or air, which thus becomes warmer; but, unlike the case of the solid, this heated layer now moves off, carrying its heat with it to other parts of the gas or liquid, and so communicating it to other matter with which it subsequently comes in contact. This method of heat transfer is known as convection, which, it will be seen, depends at bottom upon conduction, but which is at the same time conduction modified by the *movement* of a heated gas or liquid. So long as the air around us is at rest, it does not remove heat readily from the skin, since air is a poor conductor. Air in motion, on the other hand (as in fanning), cools the skin more rapidly, because as each part of the air is heated, it is moved away and replaced by colder air. In this case the air cools the skin by convection (Latin *con*, "with"; *vehere*, "to carry").

The transfer of heat from the internal heat-producing organs to the skin affords an excellent example of the difference between conduction and convection, for some of this heat passes by direct *conduction* through the subcutaneous tissue to the overlying skin, while some of it is carried to the surface by *convection* in the blood stream. When the arterioles of the skin are dilated, convection is an important means of heat transfer to the surface; when, in the reverse case, the cutaneous arterioles are constricted to their utmost, convection becomes relatively unimportant and direct conduction alone remains as the chief means of heat transfer to the skin. Moreover, when the subcutaneous tissue contains large amounts of fat, it is a poor conductor of heat, and for this reason fat people when sitting still on cold days often *feel* colder than lean people do.

Radiation. Heat is thus removed from the skin by conduction, and at times to an even greater extent by convection. But there is still a third method of heat loss, known as radiation, by which heat can be transferred across a space in which there is neither solid, liquid, nor gas, and in which conduction and convection are consequently impossible. The most familiar and striking example of radiation is the transfer of heat from the sun to the earth, since there is no atmosphere in the greater part of the more than ninety millions of miles of space which separate us from that intensely heated body.

Any detailed consideration of radiation belongs to the domain of physics rather than physiology and would be out of place here. It is enough for our present purposes to understand that, whether a solid body be in an atmosphere of air, or in a transparent liquid, or even in a vacuum, it transfers or loses heat by direct *radiation* to colder objects about it. From an open fire heat may be transferred by *conduction* to andirons or walls in direct contact with it; or by *convection* through heated air currents to the chimney top; or, finally, by *radiation* to persons standing in front of it. In the latter case the heating is chiefly by radiation, since there is no contact with the fire, and such air currents as exist are mostly composed of cool air sucked towards and into the chimney by its draft. It is for these reasons that open fires are said to "roast people in front and freeze them behind." Conversely, the human body, if warmer than its surroundings, may lose heat by conduction, convection, and radiation to cooler objects in the vicinity.

The practical importance of these facts is seldom realized. It often happens that the air in contact with the skin is of the proper room temperature; and yet, if one is sitting too near a cold wall or window, enough heat may be lost by *radiation* from the skin to the cold wall, through the warm air, to chill the skin materially, causing a loss of heat and a "cold."

Laws of conduction and radiation. For our purposes the two most important factors which determine the loss of heat by conduction and radiation are (1) the difference in the temperature of the two objects and (2) the distance between them. In general, the greater the difference of temperature, the more heat will be lost from the warmer to the colder object; thus the skin loses heat rapidly by these means when surrounding objects are at 0° F., but only slowly when they are at 90°. It is also clear that as soon as the temperature of surrounding objects and of the atmosphere is as high as that of the body (98.6° F.), no further heat can be lost by conduction and radiation; and that above 98.6° F. heat is conducted and radiated *to* the body, not *from* it.

Furthermore, the greater the *distance* of the colder object from the body, the less heat will the body lose to it. Here heat loss takes place inversely as the square of the distance; that is, when we are twice as far away from a cold (closed) window, we lose only one fourth as much heat through it by radiation; if we are three times as far away, we lose only one ninth as much, and so on. Consequently we rapidly diminish radiation from our bodies by sitting farther away from the walls of a room; and it is important to have our living rooms large enough to make it unnecessary to sit near the windows or near a cold outer wall in very cold weather.

CHAPTER XIII

NUTRITION

A. The Sources of Power and Heat for the Human Mechanism

1. Food and nutrition. In general food must meet the following fundamental needs of the body: first, it must supply power for the work of muscles, heart, etc.; second, it must give, through oxidative or other chemical change, the heat necessary to maintain the body temperature; third, it must supply all the material needed for the manufacture of everything that enters into the structure of the living cell (growth and repair) and also of the secretions, internal and external, the hormones, and all other special compounds which play any rôle in the working of the human machine. Since the first two of these functions are met by the same food material and in much the same way, we may consider first this aspect of nutrition.

2. The fuel value of food. In any locomotive engine the same amount of a given fuel will enable the engine to pull a train of the same weight for the same distance over the same track, provided, of course, the engine itself, the bearings of the wheels, etc., are in the same condition. When a ton of coal is put into the tender, it is with the expectation that it will move the train a certain distance. Thus there is a definite relation between the fuel burned and the work done. Every engineer knows also that the same weight of different fuels will carry the train different distances; a thousand pounds of wood, of bituminous coal, and of anthracite coal have different *fuel values.*

The same weight of a given fuel when burned will always yield exactly the same amount of heat, as is proved by burning the fuel under conditions which enable us to measure the heat given off. The simplest means of doing this is perhaps with the *ice calorimeter* — a metal box within which the fuel is burned, the box being everywhere surrounded by a thick layer of ice. The heat produced in burning the fuel is measured by the amount of ice melted.

In this way we may find the relative amounts of work which can be done with two different fuels, for it has been discovered by actual experiment that if one kind of fuel produces twice as much heat as another, it will also do twice as much work.

Now food is the fuel for the muscular work of the body and also for the liberation of heat. Consequently, if we determine how much heat is liberated when a certain amount of protein, or fat, or carbohydrate is burned in a calorimeter, we know how much work it *may* do in the body; or at least we know that it can do *no more* than the amount indicated by the calorimetric experiment.

3. Units of heat and work. In order to measure we must have units of measurement. Common units of length are the inch or centimeter; units of area are the square yard, the square meter, or the acre; units of volume, the quart or peck; units of weight, the pound or kilogram. We express the results of these measurements by saying that a thing is so many inches long or of so many pounds weight. What are the units of heat and work?

Like all units, these are arbitrarily chosen. *The unit of heat*, known as the *calorie*, is the amount of heat necessary to raise one kilogram of water one degree Centigrade. *The unit of work* is the amount of work done in lifting a kilogram (2.2 lb.) to the height of one meter (39.37 in.) from the surface of the earth against the attraction of gravitation. This is known as the *kilogrammeter*. Thus, when a man weighing sixty kilograms goes up a flight of stairs ten meters high, his muscles do 600 kilogrammeters of work.[1]

Finally, it has been found that the same fuel which when burned will liberate one calorie of heat will supply the power to do 423.985 kilogrammeters of work. By this we mean that not more than 423.985 kilogrammeters of work can be obtained from it. Not every engine is so perfectly constructed as to get from a certain fuel its full working capacity; indeed, most engines transform only a small fraction of the power of their fuel into work, the rest escaping as heat — in the smoke, or by radiation, conduction, and convection from the furnace, boiler, etc. But by the method above outlined it is possible to find the maximum amount of work which can be obtained from a given weight of fuel.

Applying the same methods to food, we find that

1 gram of dried *protein* yields 4.1 calories.
1 gram of dried *carbohydrate* yields 4.1 calories.
1 gram of *fat* yields 9.3 calories.

These figures are known as the *fuel values* of proteins, carbohydrates, and fats.

But the total possible power which may be obtained by actually burning a certain substance under the most favorable conditions is one thing, and the amount of power which the muscles may obtain from it is quite another. When coal is burned in an engine it does work, but the human body would get no energy for its muscular work from eating coal. So that we have now to inquire from what nutrients the muscles get their energy for work and from what nutrients the body derives its heat.

4. The power for muscular work. Few questions in physiology have been more thoroughly investigated than this. In the first half of the nineteenth century many investigators, impressed with the fact that the muscle fiber yields,

[1] Work may also be expressed in foot-pounds. (How many foot-pounds equal one kilogrammeter?)

on chemical analysis, large quantities of protein and only traces of carbohydrates and fats, believed that the energy for muscular contraction comes entirely from the consumption of the protein of the muscle substance. If this were true, it would necessarily follow that protein is the proper food to yield the energy for muscular contraction, while fats and carbohydrates would simply be oxidized to give heat.

This view was disproved by the following epoch-making experiment of physiology: Two observers determined for three successive days the nitrogen excreted by themselves; since almost all this nitrogen comes from protein, this gave the amount of protein consumed by the body. On the first and third days no vigorous muscular work was done; on the second day they climbed a mountain 1956 meters (6415 ft.) high. As one man weighed 66 kilograms and the other 76 kilograms, the work done in lifting the body to the top of the mountain in the two cases was 129,096 and 148,656 kilogrammeters respectively. The protein which was oxidized in this time could in the two cases have yielded power for only 68,690 and 68,376 kilogrammeters of work. In other words, the protein did not begin to yield sufficient power for the muscular work done in lifting the body to the top of the mountain; something else than protein must have been oxidized for that purpose, and that something must evidently have been carbohydrate or fat, or both.

Again, it was noticed that there was no increase of protein disintegration on the day of work; this remained practically unaffected by muscular contraction. Numerous other experiments made since that time have shown the same thing. Muscular exercise does not *necessarily* increase protein disintegration, and the power for it can be obtained from fats and carbohydrates.

In the experiment above referred to no determinations were made of the excretion of carbon dioxide. Since then numerous experiments have been made in which, on an abundant mixed diet, both the nitrogen and the carbon of the excretions were accurately determined. These have shown that *while muscular exercise does not necessarily increase protein disintegration, it invariably increases the production of carbon dioxide.* If the carbon of the carbon dioxide came from protein, it would be accompanied by increased excretion of nitrogen derived from the broken-down protein. The fact that it is not so accompanied can only mean that it came from the oxidation of something which did not contain nitrogen, that is, from fat or carbohydrate, or both.

But while muscular work does not necessarily or even usually increase protein decomposition, and the power for the same may be derived largely, if not entirely, from carbohydrates and fats, it has been shown conclusively that under certain conditions this power may come entirely from protein. In one experiment a large and very lean dog was fed for several weeks on an abundant diet of lean meat, containing practically no carbohydrate or fat; during this time the dog did large amounts of work in a treadmill and in other ways; and since it was found that this work could be done for weeks at a time on the meat diet, we conclude that the protein must have been the sole source of power for the work; it must also have served as the source of heat production, for the normal temperature of the animal was maintained.

5. Summary of considerations on the supply of power for work. These and other experiments show (1) that the animal body can get its energy for mechanical work and for the production of heat from protein, or from carbohydrate, or from fat; (2) that when the animal is on an abundant mixed diet, even vigorous muscular work does not increase the oxidation of protein,[1] but does enormously increase that

[1] Under the abnormal conditions of excessive muscular work (for example, six-day walking matches or bicycle races) the protein oxidation is often increased.

of carbohydrates and fats. The probable meaning of this is to be sought in the fact that protein decomposition depends primarily not on muscular work but, as we shall see later, on the amount of protein eaten; while the oxidation of fats and carbohydrates depends almost entirely on the demands of the body for energy and is largely independent of the amount of these foods eaten.

6. The supply of energy for heat production; "heating" foods. In studying the phenomena of heat production in the body we found that when the body needs more heat in order to maintain its normal temperature, this heat is supplied chiefly by greater chemical activity in the muscles (p. 209). The contraction or tone of the muscles increases in response to stimuli from the same motor nerves which stimulate them to activity when they do external mechanical work. Heat production in the body, from the standpoint of nutrition, is therefore, as far as we know, largely a case of increased muscular activity; and here, as in the case of mechanical work, the energy can be obtained from one kind of food as well as from another. Contrary to popular ideas we have no conclusive evidence that one kind of food supplies heat more readily than another. What is required in cold weather is *more food*, whether protein or carbohydrate or fat. We shall see that there are good reasons for not unduly increasing the protein of the diet under any conditions, and hence in this special case it is probably better to increase the non-nitrogenous foods to a greater extent than the proteins, though not because they are better "heating" foods.

7. The daily requirement of the body for power and heat. How many calories must be furnished the body to cover its daily needs for work and for the maintenance of its temperature? This question has been studied by several methods, but we must content ourselves with a statement of some of the most important results. Healthy people whose choice of food is not restricted by financial considerations, but is determined solely by appetite and the feeding customs of their home or community, usually consume each day food of a fuel value of 20 calories per pound of body weight. It is exceptional to find less than 16 calories or more than 24 so long as only moderate amounts of exercise are taken; and many students of this subject have assumed that one requirement of diet is that the daily intake of food should have approximately this fuel value.

This view has, however, been seriously questioned by careful and competent observers, and their work seems to show that a fuel value of 13.5 calories per pound of body weight more nearly represents the actual needs of the body. *In other words, the usual diet, with its three hearty meals a day, has a fuel value one and one half times as great as the minimum requirement of the body.* Whether the excess is or is not harmful to the body will be discussed later (see p. 239).

The chief factor which influences the amount of this minimum fuel value is the amount of muscular exercise taken. Men at hard labor require from 20 to 25 calories per pound of body weight, or even more; on the other hand, during the marked muscular relaxation of sleep the requirement is reduced to from 10 to 11 calories. Exposure to cold, when not counteracted by warm clothing, similarly increases the fuel requirement.

If, then, we generally eat more food than the fuel needs of the body require, what becomes of the excess? This question can be answered only incompletely in the present state of our knowledge. A portion of the food eaten leaves the body undigested in the feces; and the more abundant the diet, the greater is the amount lost in this way. Part of the food also is destroyed in the alimentary canal, especially in the large intestine, by microbic action, and this similarly increases with the diet. This microbic food destruction involves the liberation of heat within the body but does not yield power for work, the excess of heat being dissipated from the skin. Again, the absorption of some foods, notably proteins or their cleavage products, the amino-acids, leads to their increased destruction in the cells of the body, just as an open fire burns more vigorously when new fuel is added. Finally, food may be stored within the body. That this is true is shown by the histories of prolonged fasts in which men and women have abstained entirely from food for more than a month. Such fasters steadily lose weight, showing that the body is consuming its own substance. We may therefore pass to the consideration of the storage of material capable of meeting future nutritional needs.

B. The Food Reserve of the Body. Fat. Glycogen. Cell Proteins

8. The hoarding of inactive food material. I. The storage of fat. The most obvious reserve food stored in the animal body is fat, which may appear as drops of oil in the cytoplasm of any cell. Muscle fibers, for example, contain at times large quantities of this substance, and are then said to have undergone fatty degeneration. Under normal conditions, however, the presence of considerable quantities of fat in muscle fibers or nerve cells or most gland cells is unusual. In the cells of connective tissue, on the other hand, fat is readily stored under normal conditions, and the *adipose tissue* or fat of the body is simply connective tissue whose cells are loaded with droplets of fat. Figs. 90–92, with their explanation, will show how this takes place. But while fat may be normally stored in any of the more open connective tissues, it is especially in the subcutaneous tissue, the great omentum, the mesentery, and some other situations that its chief storage takes place. From these storehouses it is drawn upon as a reserve food material when the immediate supply of food from the alimentary canal becomes inadequate for the work of the body. The exact mechanism by which it is stored in a cell at one time and discharged at another is not fully understood. Some of the conditions under which it is accumulated, and some of those under which it disappears, are known; but we do not know the whole story. Some people lay up fat in larger quantities than others on the same diet and apparently while doing the same amount of work, and some keep lean under conditions apparently the most favorable for growing fat.

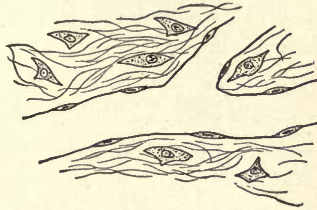


FIG. 90

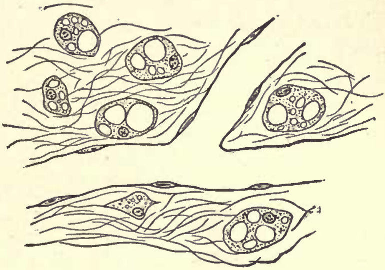


FIG. 91

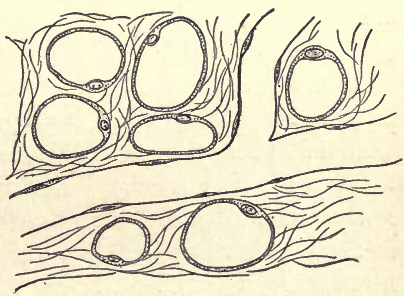


FIG. 92

FIGS. 90–92. Three successive stages in the transformation of ordinary connective tissue into adipose tissue

A portion of the capillary network is shown, surrounded by the fibers, among which are several cells. The accumulation of fat droplets in the cell cytoplasm is shown in Fig. 91, and the fusion of these upon their increase in size and number to form one large droplet, surrounded by the cytoplasm, is seen in Fig. 92

It was formerly believed, and is still sometimes supposed, that the animal body forms fat only from the fat of the food; that to get fat we must eat fat. This was disproved by a number of experiments, especially one by Liebig, who kept account over a long period of the fat in the food supplied to a cow, and found that the fat given off in the cow's milk far exceeded that in her food. In another experiment four pigs out of a litter of eight were killed and the total amount of fat in their bodies determined. The other four pigs were fattened for a time, then killed, and the fat in their bodies eventually determined. Assuming that the second set of four pigs originally had the same quantity of fat as the first four, the difference between the two quantities of fat found would give the quantity of fat the last four had stored up. Meantime, strict account had been kept of the fat supplied in the food of the last four, and it was shown that for every 100 parts of fat fed to them these pigs had laid up 472 parts of fat. They had evidently *manufactured fat from some substance other than the fat* in their food.

9. Fats can be stored from fats and carbohydrates in food. There is no doubt that fat may be both *stored away* and *manufactured* from the fats in the food. There is also no doubt that large quantities of fat may be and often are manufactured and stored from the carbohydrates (sugars, starches, etc.) of the food; so that, while there is some truth in the idea that one may get fat by eating fat, it is equally true that we can get fat by eating other foods.

10. Are proteins a source of fat? Whether fats are normally made in the body from proteins is a more difficult question. There is no undisputed case on record of such manufacture and storage; and while the facts do not yet justify us in denying the possibility, it is very doubtful whether such transformation takes place to any great extent, and it is possible that in the mammalian body it does not normally occur at all.

Fats, then, are manufactured readily from fats and carbohydrates and sparingly, if at all, from proteins. Their disappearance during starvation, when they are drawn upon to supply power and heat for the body, shows that they serve as a true reserve food material. They are a kind of food capital or hoard, saved and laid up by the body against a rainy day.

11. The hoarding of inactive food material. II. The storage of glycogen. In many cells of the body, but especially in those of the liver and to a less extent in those of the skeletal muscles, there is found a carbohydrate substance known as *glycogen.* This substance belongs to the same group of carbohydrates as starch and dextrines (see Chap. VIII), and is sometimes called *animal starch.* Like them it is changed into sugar by the action of saliva and pancreatic juice, whence its name (γλυκύς, "sweet"; -γενής, "former"). The same change occurs on the death of the cells in which it is contained, the sugar thus formed giving to such tissues a sweetish taste. This is often noticed, for example, in liver and in scallops (the shell muscle of *Pecten*). The total amount of glycogen in the human body may exceed 700 grams (13 ounces), one half of which is concentrated in the liver and the other half scattered about in the other tissues of the body.

Experiments have shown that glycogen is not formed from the fat in food; that it is formed in small quantities from protein; while its chief source is the carbohydrates of the food.

The blood may be said to be always sweet, its constant percentage of sugar (1 to 2 grams per 1000 cubic centimeters or 0.05 ounce per quart of blood plasma) being a striking fact, and one that we should hardly have anticipated. One might suppose that the sugar in the blood would increase, as does the amount of fat, during active digestion and absorption, and that after digestion had ended, it would diminish. As a matter of fact the amount of sugar in the blood remains practically constant both during and after the completion of digestion, and this despite the fact that the tissues are constantly abstracting sugar from the blood. Evidently the blood must be supplied with sugar from some other source than the alimentary canal, and there must be somewhere in the body a compensating mechanism controlling the sugar supply of the blood.

Experiments have shown that sugar is absorbed from the alimentary canal entirely by the intestinal blood vessels. It must pass, therefore, through the liver by the portal vein (see Fig. 62) before going to the rest of the body. The liver, thus standing at this great gateway to the circulation, would seem to act as the carbohydrate storehouse, or savings bank, of the body. Any excess of sugar in the portal blood is there transformed into glycogen and deposited, saved until it is needed, and then "paid out," as sugar, when the ready supply is exhausted. Other tissues doubtless aid in preventing an undue richness of sugar in the blood, acting likewise as temporary storehouses for this form of food.

12. Protein a source of sugar to the body. It has been stated that glycogen may be formed from protein. This is because the body can and does constantly form sugar (dextrose) from protein. Experiments have shown that about half of the protein may in this way be transformed into sugar, the greater part of which is ordinarily oxidized as fuel; but in case there is an excess over and above fuel needs, this excess of sugar is stored as glycogen by the liver and other organs, just as the excess of sugar absorbed from the alimentary canal is so stored. The formation of sugar, and consequently of glycogen from fat, on the other hand, is negligible.

In this formation of sugar from protein the body obviously has an additional means of supplying its carbohydrate needs when the sugar delivered to the blood by absorption from the alimentary canal is inadequate.

13. The protein reserve. Provision is thus made for a continuous supply of fat and carbohydrate (sugar) between periods of absorption of these foods and even during starvation. How are the protein needs of the body met under similar conditions? There is no visible supply of inactive protein in the body similar to fat or glycogen. It is true that analysis of the lifeless cell shows that proteins make up by far its largest constituent,[1] but there is no ground for thinking that this cell protein exists in any other form than as an active constituent of the cell substance. There is no evidence of protein stored simply as reserve to meet future possible protein needs.

And yet, during starvation, protein is steadily lost from the body, as is shown by the fact that urea and other protein derivatives continue to be eliminated by the kidneys. Nor can this loss of protein be checked by feeding carbohydrates and fats; these may be provided in the food in amounts abundantly sufficient to meet the fuel demands of the body, but without checking the loss of protein. We can only conclude that the disintegration of protein within the body is an inevitable part of the chemical activity of the cells, and that in the absence of a supply of the protein products of digestion the body takes protein from its own living substance. Hence protein becomes an indispensable article of diet. The student will, moreover, recall the fact that while carbohydrates and possibly fats may be made from protein, protein cannot be manufactured from the non-protein nutrients. This obviously follows from the fact that fats and carbohydrates are lacking in nitrogen and sulphur, two essential elements of the protein molecule.

14. Increase of protein in the food increases protein destruction by the body. One peculiarity of the behavior of protein in the body of itself limits the accumulation of any large amount of storage protein. As soon as we increase the protein of the food, there is an increase of protein disintegration in the body, and in a few days protein disintegration equals

[1] The following analysis of muscle cells (lean of meat) is typical:

Water	75 parts
Solids	25 parts
Protein	21 parts
Salts	1 part
Fat, connective tissue, etc.	2 parts
Other extractives	1 part

the greater protein consumption. Instead of storing the additional food protein or even part of it over any great length of time, the body soon comes to destroy all the protein eaten. It is for this reason that while animals may be fattened to a remarkable extent by proper feeding, it is not possible to secure a corresponding increase of protein material of the muscle, or lean meat. The accumulation of protein is self-limited.

In two physiological states the increase of protein is much more marked; namely, during growth and during convalescence from wasting disease (or after a period of prolonged fasting). It would seem that there is a certain maximum content of protein-like substances in the cell, and that it is not possible by the most abundant feeding to increase this amount.

It follows from the above that very abundant protein feeding must result in the production of increased protein waste within the body. In the first place, the greater the quantity of protein fed, the greater will be the microbic destruction of protein within the intestine and especially in the large intestine. Not only is the protein so destroyed largely useless to the body, but, in so far as its microbic destruction involves putrefactive changes, harmful products may be formed from it. In the second place, that portion of the protein which escapes microbic action and is absorbed into the blood in the form of digestive products (amino-acids and peptids) disintegrates in the cells with the formation of wastes. Both these processes increase the amount of waste to be eliminated, chiefly by the kidneys. It has been urged that this overburdens the kidneys and causes disease of these organs. While convincing proof has perhaps not been given that a healthy kidney may be injured in this way, it is certain that a diseased or even a temporarily impaired kidney may suffer when such excessive work is thrown upon it.

C. Food as the Material for Growth, Repair, and the Manufacture of Special Products of Cell Activity

15. Complexity of the chemical composition of living cells and of the products of their manufacture. In the first subdivision of this chapter we have considered food as fuel. We are now in a position to consider some of the more important features of the other great function of food, namely as the material for the growth and repair of living cells and for the manufacture of the special products of cell life — the secretions (internal and external), the hormones, and all other substances produced by the body for special purposes.

The living cell is an extremely complex machine into the construction of which enter numerous compounds of diverse chemical nature. Formerly there was a tendency to regard the cell as composed essentially of protein; but the increase of our knowledge has shown that there are other essential constituents, notably (in addition to water and inorganic salts) a group of compounds known as lipoids, or lipins, substances which more or less resemble fats in their physical characters, although not always in chemical structure. The cell nucleus also contains special material of still different chemical composition. The chemical properties and the physiological significance of these cell components are far too complicated subjects for discussion in this work; we merely wish to emphasize the complexity of the mixture and the variety of chemical compounds concerned. (See p. 42.)

We are impressed with the same diversity of chemical structure in the secretions, hormones, and other material manufactured by the body for special purposes. The student has only to recall the examples of these already mentioned — the enzymes of the digestive juices; the internal secretions of the adrenals, thyroids, pituitary, and pancreas;

secretin and other hormones; mucin; hemoglobin — to realize that the food must furnish material out of which to manufacture compounds of the greatest variety of chemical structure; and for this purpose the greatest variety of material must be furnished in the food.

16. The unique position of protein. Considerations such as the above give a glimpse into the unique value of protein food. While all forms of carbohydrate yield the body, for the greater part, only dextrose, and the fats yield only fatty acids and soaps, all of them closely similar in structure, protein yields amino-acids of the greatest diversity of chemical structure. The possibilities of chemical construction, or *synthesis* (as it is generally called), are thereby greatly increased. Only a chemically complex food like protein could serve for the construction of the proteins of the living cell and for the formation of the varied products of cell manufacture. Review in this connection section 15 of Chapter VIII.

Protein is also unique among the nutrients in the fact that the body can make other nutrients from it. It is a well-established fact that large quantities of sugar (dextrose) may be made from protein, and we can therefore understand how a dog living on fat and the leanest sort of meat (protein) can do without carbohydrate in the diet. It is also possible that at least small amounts of fat may be derived from protein through this intermediate stage of sugar, for fat may be made from sugar.

17. Variations in the nutritional value of individual proteins. Until comparatively recent times all food proteins were regarded as having equal value in nutrition, with the single exception of gelatin, which has long been known to be incapable of meeting the protein needs of the body. The discovery that some food proteins are lacking in one or more of the amino-acids, and that the same amino-acid may occur in very small amounts in one protein and very large amounts in another, suggested to two American physiologists, Mendel and Osborne, the idea that different proteins may have very different values in nutrition. They therefore fed rats and mice on diets of abundant fuel value and containing all the non-protein constituents of the diet, but containing only one protein. It was found that some proteins failed entirely to nourish the animal, as shown by the steady loss of weight; others would keep an adult animal in good condition with no loss of weight, but did not provide the material for the normal growth of young animals; other proteins not only maintained the normal weight of the adult but a young animal fed on them would grow in a perfectly normal manner. We must therefore distinguish between (1) proteins which may provide for both growth and maintenance, (2) proteins which will provide for maintenance but not for growth, and (3) proteins which will provide for neither maintenance nor growth.

Further study showed that the nutritional limitations of the last two classes of proteins are due to the fact that they are lacking in certain amino-acids or else contain them in very small amounts; for if these amino-acids were added to the diet, growth and maintenance became normal. The reason for this becomes clear on the assumption already made in our discussions of digestion and nutrition, that the value of protein as food lies in the fact that it yields a great variety of amino-acids, each necessary to some chemical manufacturing process of the living cell.

18. The value of the mixed diet. As a matter of fact no one tries to live on a single protein. Meat contains at least two; eggs, three or more; milk, two; the cereals, two or more each. By taking a mixture of these in our food, the deficiency of one protein in amino-acids is made up by the excess of the same acid in another. For this reason we can completely meet the protein needs of the body on a mixed diet with a far smaller total intake of protein than if the diet contained only one protein.

The same consideration applies in a larger way to the food as a whole. Some foods, like meat, are chiefly protein; others, like the cereals, have an excess of starch, while others, like butter or olive oil, are chiefly fat. A diet composed of several kinds of food, that is, a mixed diet, is more likely to avoid an excess of any one nutrient than when any one food unduly preponderates.

19. Other indispensable constituents of the food. I. Inorganic salts. In addition to the proteins, fats, and carbohydrates, which together make up almost the whole (96 to 98 per cent or even more) of the food we eat, two other groups of substances are required in much smaller quantities, but they are none the less absolutely indispensable. The first of these is the group of inorganic salts. In the body are found chlorides, carbonates, and phosphates of sodium, potassium, calcium, and magnesium. These occur both in the living cells and in the blood and lymph, and they are constantly being removed from the blood in the urine and perspiration. This loss must be made good by the food. Most foods contain salts, and our usual food contains most of the inorganic salt necessary for making good the loss. The table salt used in cooking and to develop the flavor of food at table is for the greater part in excess of the actual needs of the body, the excess being promptly excreted by the kidneys. The addition of some salt, however, seems to be necessary. The craving of herbivorous animals for salt in which their food is deficient is well known, and in parts of India salt famines have occurred during which the price of salt was higher than that of gold.

20. Other indispensable constituents of the food. II. "Vitamines." Finally, it is known that certain other compounds, found in small quantities in many foods, are necessary for adequate nourishment. The exact chemical nature of these substances is still a matter of investigation, but it is known that they are neither protein, fat, carbohydrate, nor inorganic salts. They occur in the outer layers of cereal grains, such as wheat, rice, oats, etc.; they are also present in most fresh vegetables and, in smaller quantities, in meats, eggs, and milk; and they are produced by the yeast plant during its active growth. Hence they may be extracted from yeast cakes. To them the general name of *vitamines* has been given.

In many Eastern countries, where rice forms the chief article of diet, a severe disease known as beriberi is more or less common. It is characterized by grave disorders of nutrition, and in severe forms the nerve fibers undergo degeneration, so that paralysis of the skeletal muscles develops. It was found that beriberi occurred chiefly among those who used polished rice, that is, rice from which the dark outer portion of the grain had been removed in the process of milling, in order to give a whiter rice grain; it seldom developed in those using the whole rice grain (that is, the unpolished rice). It was furthermore found that from the rice polishings something could be extracted which when administered in very small quantities would cure the disease. Finally, it was found that a similar disease (polyneuritis) could easily be induced in fowls by feeding them on a diet consisting solely of polished rice, but that it did not develop when the extract of rice polishings was administered to the fowls even though their food otherwise consisted wholly of polished rice. This extract would, moreover, cure the disease when it had once developed.

Whether one group or more than one group of compounds is concerned here is not known. It is clear, however, that we have in the above facts proof of some essential constituent or constituents of the diet other than the usual nutrients. These vitamines seem to occur abundantly in most fresh fruits and freshly cooked vegetables and in the outer portion of most cereal grains. They are destroyed by very high temperatures, especially those used in sterilizing canned foods, and they are largely removed from the cereal grains in the attempt of the miller to produce the whitest possible flour or rice, for this means the removal of the outer portion (bran) of the grain with its vitamines. It follows that "whole wheat" flour or graham flour contains these substances, while very white flour is deficient in them; and we accordingly find that the same disease (beriberi) has occurred in Newfoundland, where a community was shut off during winter from its usual food supply and white bread constituted for too long a time the chief food. A similar and probably identical disease has been found among people living exclusively upon canned goods, the sterilization by high temperatures having destroyed the vitamines.

In the days of sailing vessels, scurvy, a disease of malnutrition, often developed on long voyages, despite a diet which contained an abundance of protein, fat, carbohydrate, and salt; and it was found that this disease could be prevented by the use of fresh limes or freshly cooked vegetables. There is little doubt that here again we are dealing with a disease analogous to beriberi.

In all the above cases it must be clearly understood that there is no harmful constituent in the foods mentioned — canned foods, polished rice, white bread, and the like. The trouble lies in the absence from the food of an essential constituent of the diet. No harm would result, for example, from a diet of canned meat, white bread, and fresh vegetables; for the fresh vegetables would supply the necessary vitamines. It is only when the diet consists almost exclusively of foods deficient in vitamines that trouble results.

The physiological action of these vitamines is not yet clear, but we are probably not far from the truth if we regard them as furnishing the body with some material indispensable for carrying out the processes of chemical manufacture. Though required in much smaller quantities, they are as necessary to these processes as the amino-acids themselves.

D. The Proper Daily Intake of Protein

21. The economic and the physiological question. The proper amount of protein in the diet is both economically and physiologically important. Since foods rich in protein — meats, eggs, dairy products, etc. — are among the more expensive foods, it is often for a family with limited income a practical question how much of these foods must be used to assure proper nourishment of the body. In this work we are more directly concerned with the physiological effects of low, moderate, and abundant protein diet, but the answer to this question also gives the answer to the economic question, since the problem in the latter case is to keep down the consumption of the more expensive foods to the level which is consistent with adequate nutrition.

It is comparatively easy to determine whether the fuel value of the diet is adequate. If it is insufficient, loss of weight inevitably results; if it is excessive, and especially if it is excessive in fat and carbohydrate, there is apt to be increase of weight. An equilibrium of total intake and output for months usually indicates that the fuel needs of the body are being met. Equality of intake and output of protein, on the other hand, does not prove that the protein of the diet is what it should be, for the body breaks down all the protein it consumes whether the amount be excessive or not. We can, however, determine by dietary studies what is the usual consumption of protein by different classes of people and also what is the lowest intake upon which protein equilibrium may be maintained in the body.

22. The usual and the minimum intake of protein. When the choice of food is not restricted by economic or other consideration, but is determined solely by appetite or the feeding customs of one's home or community, the protein intake of an adult healthy man usually varies between 100 and 150 grams daily. This is equivalent to from 500 to

750 grams (1 to $1\frac{1}{2}$ pounds) of lean meat, although of course the protein is not all taken in the form of meat. On the other hand, experiments have shown that men may live for years in good health on a protein intake of from 40 to 50 grams daily without loss of protein from the body.

If then an adult man can maintain protein equilibrium on from 40 to 50 grams of protein daily, but ordinarily consumes two to three times this quantity, the question arises whether the additional 50 to 100 grams are in any way harmful. Many students of this subject have strongly taken the position that such is the case, and there can be no question that the health of many people, especially when leading sedentary lives, has been greatly improved by reducing the consumption of protein to 60 or 70 grams, or even to 40 or 50 grams daily. To what is this improvement due? Is it because the handling of so much protein by the adult is necessarily harmful? (See p. 239.)

23. Possible harm and possible advantage in an abundant protein diet. We can readily see at least two ways in which the greater protein intake may be harmful. In the first place, it involves greater danger of incomplete protein digestion in the small intestine and the consequent delivery by peristalsis of excessive amounts of protein to undergo microbic putrefaction in the large intestine. In general the presence of a decidedly offensive odor to the feces suggests that more protein[1] is being eaten than can be properly digested, and justifies at least an experimental reduction in the protein of the food. It must, however, be remembered that putrefactive odors may be due to other causes than excessive protein diet (impaired digestion of fats, for example) and, on the other hand, there may be excessive putrefaction and yet the feces have no very offensive odor because the compounds responsible therefor have been destroyed within the body.

[1] The substances responsible for the offensive odor are almost entirely derivatives of protein.

In the second place, the larger protein diet with its increase of protein wastes in the body itself (as contrasted with the alimentary canal) involves a greater burden on the organs of excretion. This burden may fall not alone on the kidneys, which finally discharge these wastes from the body, but also upon other organs in which the waste products are prepared for final removal from the blood by the kidneys. Convincing proof has, however, not been given that these organs, when in a healthy condition, are injured by the work of caring for more than the waste of a low protein diet. A somewhat analogous case is that of muscular activity. This, too, must be limited or even given up altogether in some diseased conditions lest some undue burden be placed upon the organism; but in health the body is actually benefited by the "burden" of even vigorous muscular activity.

The further question then arises whether there is any possible advantage in a liberal protein diet. It is certainly not needed for power or for fuel; it may, however, be plausibly urged that thereby we insure an abundance of each amino-acid needed for the formation of the innumerable products of chemical manufacture in the body. When an engineer builds a bridge, he does not build it just strong enough to sustain the expected load; he allows a liberal "margin of safety." Similarly, it is not a desirable economic condition when one's income each week is just enough to meet necessary expenses, for this does not allow for the unexpected emergency which we cannot foresee. So it has been urged and, it would seem, reasonably urged that it is better not to diminish protein intake, as a rule, to the irreducible minimum of 40 to 50 grams daily. While 100 to 150 grams is almost certainly far more than is necessary to secure the proper margin of safety, it may well be wiser to use 20 or more grams above the minimum; that is to say, a protein intake of 70 grams corresponds with what, in the present state of our knowledge, may be regarded as a conservative estimate.

Infants and rapidly growing children need relatively more protein than adults. The protein of the usual adult diet makes about 13 to 15 per cent of the total fuel value of the food; in milk, the sole diet of a baby, it makes 20 to 25 per cent. A similar thing is true of the diet during convalescence from wasting diseases; such a diet should be as rich in protein as is consistent with its proper digestion and utilization by the body.

24. Food values of some common foods. The following table (from Joslin) will be found useful in forming an estimate of the content of certain foods in protein, fat, and carbohydrate, and also of the fuel value of these foods.

30 Grams (or 1 Ounce) contain Approximately	Protein	Fat	Carbohydrate	Calories
	Grams	*Grams*	*Grams*	
Oatmeal, dry weight	5	2	20	120
Cream, 40 per cent	1	12	1	120
Cream, 20 per cent	1	6	1	60
Milk	1	1	1.5	20
Brazil nuts	5	20	2	210
Oysters (six)	6	1	4	50
Meat (uncooked, lean) . . .	6	3	0	50
Meat (cooked, lean)	8	5	0	75
Bacon	5	15	0	155
Egg (one)	6	6	0	75
Vegetables (5 and 10 per cent groups)	0.5	0	1 or 2	6 or 10
Potato	1	0	6	25
Bread	3	0	18	90
Butter	0	25	0	225
Fish	5	0	0	20
Broth	0.7	0	0	3
Small orange or half a grapefruit	0	0	10	40

An individual "at rest" requires about 25 calories per kilogram (2.2 lb.) body weight per 24 hours, equivalent to approximately 1 calorie per kilogram per hour.

25. Example of a diet of moderately low protein and fuel value. The following table gives an example of three meals which would give the moderate protein intake referred to on page 237. The fuel value also corresponds approximately, for a man of 150 to 160 pounds, to the fuel value of 13.5 calories per pound of body weight referred to on page 221.

Breakfast. Bread, 38.7 grams; tea, 146 grams.

Lunch. Bread, 97.5 grams; butter, 31.5 grams; sweet potato, 108.7 grams; spaghetti, 82.5 grams; peaches, 89.4 grams; coffee, 210 grams; sugar, 21 grams.

Dinner. Bread, 75 grams; butter, 21.5 grams; roast beef, 116 grams; lemon pie, 188.5 grams; coffee, 210 grams; sugar, 21 grams.

Protein in food	70 grams
Fuel value	2334 calories

30 grams = 1 ounce, or $\frac{1}{16}$ pint.

CHAPTER XIV

SENSE ORGANS AND SENSATIONS

1. The human mechanism a conscious mechanism. Thus far we have repeatedly compared the human mechanism with lifeless mechanisms, and the points of similarity are most interesting and instructive. In the supply of power, the elimination of wastes, the interdependence and coöperation of parts, the adjustment to the changing conditions of work, and in many other respects the resemblance holds good. But in one respect there is no likeness whatever. When a human mechanism is not in good working order or is tired, it may be aware of the fact; when an engine is damaged in any way, the engine does not know it. Events taking place in the living animal body arouse in it, and in it only, *conscious sensations.*

Sensations are always called forth by the condition of some organ or by the condition of the body as a whole. When several hours have passed since the taking of food, we feel hungry; or of drink, we feel thirsty; when anything touches the skin a sensation of touch is aroused; if it presses very hard, that part of the skin feels painful; if the tongue is acted upon by sugar or salt, we get a sensation of taste; if light enters the eye, it produces conditions in that organ which arouse in us sensations of color. *In all these cases the conscious sensation is due to the condition of some part of the body.*

2. The reference of sensations. Sometimes we refer the sensation to the part of the body which is first affected, or to the body as a whole, and sometimes we refer it to external objects. Thus, if in driving a nail the hammer misses the nail and hits a finger, we refer the pain to the finger and not to the hammer; and we similarly refer sensations of hunger and thirst to the body and not to external objects. If, on the other hand, the skin is cooled by a piece of ice, we do not say that the skin is cold, but that the ice is cold; we refer the sensation to the external object which causes it, not to the skin in which it actually originates. In the case of the sense of sight, this reference of the sensation to the external object which sends light into the eye is so complete that unless we stop and reflect upon it we do not realize that it is the condition of the eye of which we are conscious rather than the condition of the external object at which we are looking.

3. Sense organs. A few sensations, like pain, are aroused by the condition of most, if not all, parts of the body; there is no one organ set apart to produce them. Some, like hunger, although at times more or less general in origin, are commonly aroused by the condition of some one organ [1] which ordinarily performs other functions. Other sensations arise in organs set apart for the purpose and constructed to react to only one kind of stimulus (*special sense organs*, or organs of special sensation). To this latter class belong the eye, the ear, the olfactory mucous membrane of the nose, the touch organs in the skin, etc. We therefore speak of *general sensations* and *special senses*, although no sharp line of division can be drawn between the two.

4. The brain the seat of sensation. In all cases, however, the sensation, although originating elsewhere, is developed in the brain and not in the sense organ. If the optic nerve be cut, blindness ensues, although light falling on the retina produces the same effect in the eye itself as when the nerve is intact; it even starts nervous impulses toward the brain; but, since these impulses go no farther than the cut, they

[1] In the case of hunger, the stomach.

excite no sensation of light. And the same thing is true of other sensations. Conversely, after the amputation of a limb it often happens that sensations are felt, as if they came from the lost member. In this case the stump of the cut nerve is stimulated in some way, and the impulses thus sent to the brain excite the same sensations as if they came from the usual endings of the nerve. When one hits his "funny" or "crazy" bone (that is, directly stimulates the ulnar nerve) the sensations developed in the brain may be referred to the fingers in which the nerve originates.

In the development of every sensation, therefore, we have to distinguish between (1) what takes place in the sense organ or end organ, (2) the passage of a nervous impulse from this organ to the central nervous system, and (3) the events which the arrival of the nervous impulse excites in the brain. It is only the last (3) that, strictly speaking, we can call *sensation.* The sense organs and their afferent fibers are merely tributary mechanisms which serve to excite the sensations in the brain. We are not aware that it is the brain which is thus active, for we refer the sensation either to the organ or to some external object.

5. The sense of sight; the eye. Sight is one of the most highly specialized of the senses. The eye is the only organ in which originate sensations of light or color, and it is a wonderfully constructed apparatus, the function of which is to stimulate the optic nerve by rays of light. It is essentially a living camera in which, by means of a lens, an image of things around us is formed upon the retina; just as in the photographer's camera the lens forms an image on the ground glass or on the sensitive plate or film.

6. Structure of the eye. The eyeball consists of three concentric coats surrounding and inclosing transparent substances through which rays of light pass to the retina. The outer, or *sclerotic*, coat (the white of the eye) is composed of very tough, dense connective tissue, and forms the protecting covering of the eye. Over a small area in front this coat is transparent, and this part of it is known as the *cornea.* Inside the sclerotic is the middle coat, or *choroid*, richly supplied with blood vessels and containing in its connective tissue large quantities of black pigment, which prevents the passage of light into the eyeball except through the cornea. The choroid lines the sclerotic everywhere except in front, where in the region of the cornea it leaves the sclerotic and projects toward the long axis of the eye as a kind of curtain, the *iris* — that part of the eye which is black or gray or blue. The *pupil* is the dark round opening, or hole, in the iris. Immediately inside the choroid is the third and innermost coat, the *retina.* This is a thin membrane, not more than one eightieth of an inch in thickness, and lining the chamber of the vitreous humor as far forward as the ciliary region (Fig. 93). The retina is the part of the eye sensitive to the stimulation of light. Here also begin the fibers of the *optic nerve*, which passes through and perforates the choroid and sclerotic coats behind on its way from the retina to the brain. These and other parts of the eye may be easily seen by dissecting the eye of an ox or sheep.

7. The lens and the muscle of accommodation. Immediately behind the pupil is the *lens*, a biconvex, transparent, compressible, and elastic body fastened by a circular ligamentous sheet *to the choroid coat* immediately above and behind the iris. The lens and its suspensory ligamentous sheet thus divide the eye into two distinct chambers: the one, in front of the lens and behind the cornea, filled with a watery fluid, the *aqueous humor*; the other, behind the lens and surrounded by the retina, filled with a jellylike, transparent substance, the *vitreous humor* (Figs. 93, 96).

The elastic choroid coat is not long enough to reach around and inclose the vitreous humor without stretching, and hence it constantly exerts a steady, elastic pull or tension on the ligament of the lens. This tension flattens the compressible lens (that is, makes it less convex), and the lens is always in this flattened condition in the resting eye; for example, when one is asleep. The same condition should obtain, as we shall learn, whenever we are looking at distant objects.

The pull of the tense choroid on the lens is, however, overcome at times by the action of the sheetlike *ciliary muscle.* The fibers of this peculiar muscle originate in the sclerotic coat around and just outside the cornea, and diverge radially outward and backward to end in the choroid beyond the attachment of the suspensory ligament of the lens. Fig. 94 shows how the contraction of this muscle, fixed as it is near the cornea, must draw the choroid forward and so ease the pull of the latter on the ligament of the lens. When this happens, the lens, owing to its own elasticity, assumes its independent (more convex) shape.

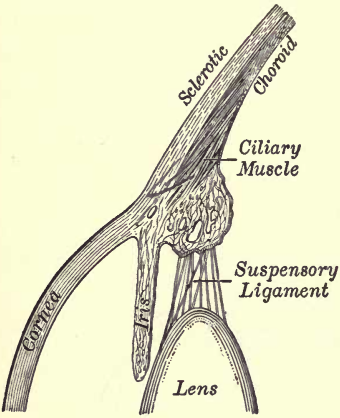


FIG. 93. Vertical section through the ciliary region of the eye

Showing the structures concerned in accommodation (see sect. 7). This should be compared with the perspective view into the hemisphere of the eyeball, shown in Fig. 167

The curvature of the lens is thus variable, and is determined by the action of this muscle of accommodation. When the ciliary muscle is relaxed, the lens is kept flattened by the pull of the choroid on the ligament; when the muscle contracts, this pull is eased off (or slacked) and the lens becomes more convex. The entire operation is known as *accommodation*, and we may now inquire what part accommodation plays in vision.

8. The formation of an image by a lens. The eye is a camera, in that it forms on the retina an image of objects in front of the cornea; and it is the first essential of clear vision, just as it is the first essential of photography, that this image be sharp, or at least distinct. A simple experiment will show that clear vision of near and of distant objects cannot be had by the eye at the same time. Hold up a pencil or a pen about ten inches from the eye and look first at it and then at some object far away. Both can be seen, but only one at a time clearly, and often *an effort is required to shift from the far to the near object.*

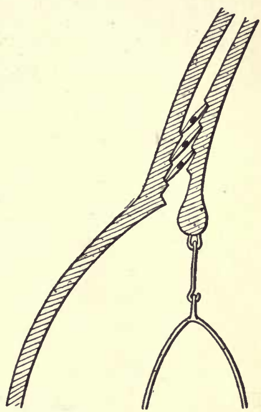


FIG. 94. Diagram of the mechanism of accommodation

The ciliary muscle is represented as three fibers passing obliquely from the sclerotic to the choroid

The change which occurs in the eye in the act of accommodation is illustrated in the following experiment: A wooden or pasteboard box (approximately 8 by 5 by 4 inches) is fitted with a piece of ground glass on one side and provided with a convex lens on the opposite side. This is a rude camera, and some object is now placed at such a distance that the lens forms an image of it on the ground glass, which is now in focus for the object. If, later, the object be moved nearer to the lens, the focus is changed; the image on the glass becomes blurred, and in order to make it distinct it will be found necessary to use a more convex lens.

Essentially the same change occurs in the eye in accommodating for near objects: *the lens must be made more convex*; and this, it will be remembered, involves work on the part of the muscle of accommodation (see p. 244). We can thus understand why, in general, it is too much of "near work," and especially near work necessitating very distinct vision, that tires the eye. The ideal condition of the eye, regarded merely as a camera, is that in which distant objects are focused on the retina when the muscle of accommodation is completely relaxed and the lens is thus flattened to its utmost by the elastic pull of the choroid coat (p. 243), for in this case the eye is rested by looking at distant objects, and works only when looking at near objects. Such an eye is known as an *emmetropic* eye (Fig. 97, *E*).

Unfortunately, not all eyes meet this requirement. The eyeball may be either too short or too long; so that, with the muscle of accommodation relaxed, the position of the

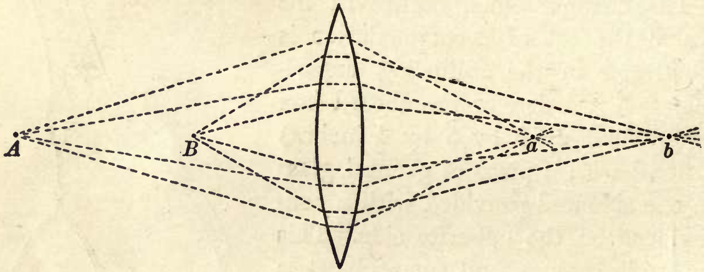


Fig. 95. Action of a convex lens in bringing to a focus the rays of light diverging from a single point

The rays from *A* are focused at *a*; those from *B*, at *b*

perfect focus for distant objects is either before or behind the retina; the eye no longer sees distant objects distinctly when it is at rest, because then the retinal image is blurred. To understand more fully the undesirable consequences of this condition, we must learn how convex lenses produce images of objects.

9. The action of a convex lens on rays of light. The rays of light diverging *from a single point* and entering a convex lens are bent so that all come together again in a point behind the lens, or, as it is said, are brought to a *focus*. This is shown in Fig. 95, as is also the fact that rays of light diverging from more distant points come to a focus behind the lens sooner than those diverging from nearer points.

Now a lens forms an image of an object because all the rays of light from each point of the object are focused in corresponding points behind the lens. This is shown in Fig. 96, where all the rays diverging from 1 are focused at 1′, all those from 2 at 2′, and those from intermediate points of the object at intermediate points of the image.

If the rays from each point meet in front of the retina and then diverge before reaching the retina, the retinal image is blurred; and the image is also blurred if the retina is so

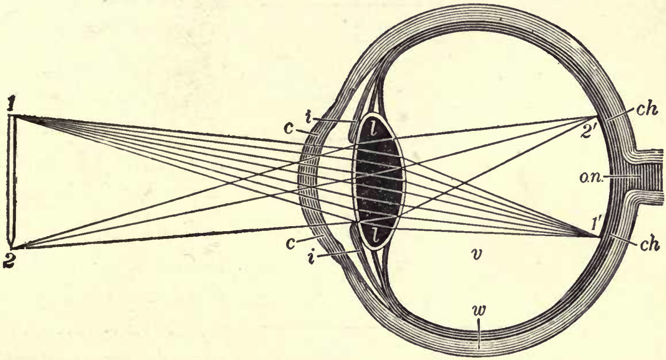


Fig. 96. Diagram showing the formation of an image on the retina
***1, 2*, the object; *1′, 2′*, the image of the object; *c*, cornea; *i*, iris; *l*, lens; *v*, vitreous humor; *w*, sclerotic; *ch*, choroid; *o. n.*, optic nerve**

near the lens that the rays from each point have not yet come to a focus. The more convex the lens, the more will the rays of light be bent; consequently we use the muscle of accommodation (which makes the lens more convex) to get clear images of near objects (see Fig. 95).

10. Myopia, hypermetropia, and presbyopia. In the emmetropic eye (Fig. 97, *E*) the distance between the retina and the lens is such that light from distant points comes to a focus on the retina without any active muscular accommodation; to see near objects the lens is made more convex.

When the retina is so far away from the lens that, with the muscle of accommodation completely relaxed and therefore the lens flattened to its utmost, light from distant points comes to a focus in front of the retina, the retinal image is blurred, and it is impossible for such an eye to see distant objects clearly. To correct such vision it would be necessary to make the lens *still less* convex, and this the eye is unable to do. (Why?) Such an eye is known as *myopic*, or *nearsighted*, and its defect must be corrected by the use of *concave* glasses, which act as if the lens were made flatter, and so throw the focus farther back upon the retina. A myopic eye generally has clear sight for very near objects because, as stated above, the nearer the object the farther back is the image formed.

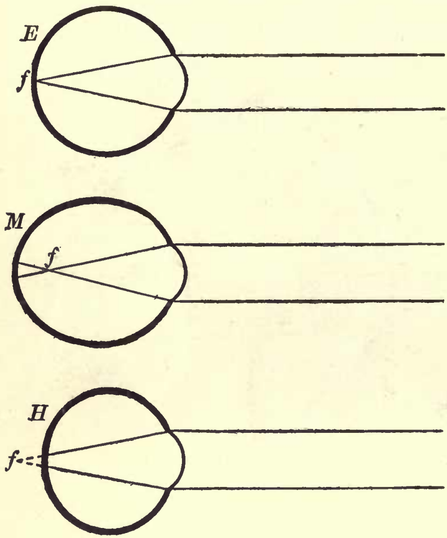


FIG. 97. Course of the rays of light from a distant point

Through the emmetropic (E), the myopic (M), and the hypermetropic (H) eye, the muscle of accommodation being relaxed. (The rays diverging from a distant point would enter the eye practically parallel)

On the other hand, the eyeball may be too short, fore and aft (Fig. 97, H), so that, when the ciliary muscle is relaxed, light from distant points has not yet been brought to a focus when it reaches the retina (*hypermetropia*). Such an eye must accommodate not only for near but also for distant objects, and its muscle of accommodation can never rest so long as the eye is being used. Moreover, to see near objects the ciliary muscle must work much harder than in the normal eye, and it often happens that, even with its utmost effort, the rays are not sufficiently bent to focus them on the retina; so that a book, for example, must be held at arm's length to be read. Persons having such eyes form one class of those said to be "far-sighted," and their trouble can be corrected by the use of *convex* glasses.

As old age approaches, changes occur in the lens; in consequence, it no longer becomes as convex as formerly in response to the action of the muscle of accommodation (*presbyopia*, from πρέσβυς, "old"). Some, though not all, results of this condition resemble those of hypermetropia; but the two differ in cause. Hypermetropia is due to *shortness of eyeball*; presbyopia, to *failure of accommodation.*

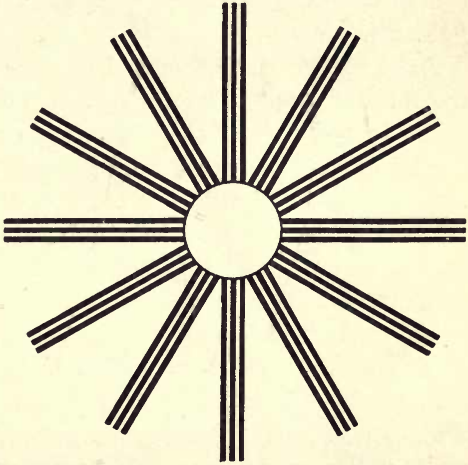


FIG. 98. A test for astigmatism

11. Astigmatism. We have thus far been dealing with those optical imperfections due to improper distance between the lens and the retina. Another and frequently more serious trouble, known as astigmatism, results when the curvature of the cornea (and sometimes of the lens) is not perfectly regular; that is, when these surfaces are not segments of perfect spheres, but resemble in curvature the side of a lemon. In this case the rays of light from a point are not brought to a focus again in a point behind the lens; and remembering the importance of sharp focusing in securing distinct retinal images, the student will see that this defect must seriously interfere with clear vision. The optics of astigmatism are too complicated to be explained in an elementary work, but the defect reveals itself generally in an inability to see with equal clearness lines running in different directions. Thus some of the lines in Fig. 98 will be sharply defined and black while one is looking with one eye at the white center, and others will be blurred and lighter in color.

Astigmatism is of special importance in reading, because the lines of printed letters run in different directions. The effort to see clearly the printed page is often severe, and results in headaches and other general disturbances of health, the true cause of which is often unsuspected. The trouble may usually be corrected by the use of so-called "cylindrical" glasses; that is, glasses which compensate the defects of curvature in lens and cornea.

12. Accommodation and "near" work. The above-described defects of the eye as an optical instrument may usually be successfully corrected by the use of proper glasses, which should, generally speaking, be prescribed by a good oculist and not by an optician. Glasses may be used for various reasons — as a matter of convenience, as where a person with slight myopia wears them merely to see distant objects clearly; or of necessity, as when the myopia is more pronounced; or they may serve the much more important purpose of relieving the muscle of accommodation of undue work in reading or sewing, and thus of avoiding "eyestrain." A hypermetropic eye should always be provided with glasses, since otherwise its muscle of accommodation cannot be rested by looking at distant objects. But since it is near work which requires the greatest effort of accommodation, it is in reading, writing, drawing, sewing, etc. that the eyestrain is apt to be greatest. As this kind of work is constantly increasing in modern life, the need for the complete correction of such defects becomes more and more necessary. Those whose occupations require long-continued use of the eyes should see to it that these precious organs are used only under the most favorable conditions and that all strain is as far as possible relieved.

13. Accommodation involves nervous as well as muscular work; the importance of sharp contrast. The work of the muscle of accommodation is controlled by the nervous system, and accurate accommodation involves an unusually high degree of nervous coördination. The strain thus imposed may be lessened not only by the use of proper lenses and by giving the mechanism of accommodation periods of rest (by looking for a time at distant objects) but also by using the eyes in near work under the most favorable conditions. Perhaps the most important principle involved here is to secure the greatest possible contrast between the light and dark parts of objects at which we are looking. When the contrast is marked, the objects can be seen easily and recognized even though the accommodation is not absolutely perfect. When, on the other hand, the contrast is not great, very accurate accommodation is necessary. Important means of securing the maximum contrast are the following:

1. *The avoidance of too little and of too great illumination of the object.* Let the student examine any printed page with different degrees of illumination. The contrast of white and black will be poor in dim and in very bright lights, and greatest with a certain moderate illumination. Hence reading in twilight or with sunlight falling directly on the page means greater eyestrain.

2. *The avoidance of a flickering light.* A steady light — one free from flicker — is of the highest importance for near work. In this respect a good kerosene lamp (student's lamp or Rochester burner) is perhaps the best of all lights for reading, provided the heat which it gives off is not too great. Electric lights are good if steady, but too frequently

they are not. Gas from an ordinary fishtail burner is one of the poorest lights for reading and sewing. The flicker of gas lights may, however, be largely avoided by the use of mantles.

3. *If the printed matter is not held steady*, the effort of accommodation becomes much more difficult. Consequently it is in general a bad thing to read, and especially to read fine or poorly printed matter, on any but the steadiest railroad train.

4. *The use of very fine type* should be reduced to a minimum. When such printed matter is held at the ordinary distance of eighteen inches from the eye, very accurate accommodation is needed, and this, we have just seen, involves nervous strain; if it is held closer to the eye (so as to make a larger image on the retina) the lens must be made much more convex to focus it, and this means excessive work on the part of the muscle of accommodation. This is very undesirable, and especially so in youth, since then the tissues of the eye are more plastic, and excessive strain of the muscle of accommodation, pulling as it does on the sclerotic and the choroid coats, may lead to permanent deformation of the curved surfaces. The marked increase of myopia within the past forty or fifty years is generally explained in this way.

5. *Highly calendered paper objectionable.* Closely connected with the size of the type is the character of the paper on which it is printed. This should be as dull as possible in order to avoid the confusing effect of a glossy surface. The use of highly calendered paper in many books and serial publications, because such paper lends itself more readily to the reproduction of pictures in half tone, is a sacrifice of hygienic considerations to cheapness.

14. Visual sensations. We have shown (p. 241) that the sensation of sight does not develop in the eye, but in the brain, as the result of nervous impulses sent thither over the fibers of the optic nerve from the retina. Just how the light falling upon the retina originates these impulses cannot be discussed here; suffice it to say that the character of the impulse differs according to the color of the light[1] stimulating the retina; the lens focuses upon the retina a *flat*, *colored* picture of the objects at which it is looking, just as a photographic camera does, or as the painter represents a scene on canvas. One part of the retina is thus stimulated by light of one color, and another part by light of another color or by another shade of the same color; and the different kinds of impulses started in the fibers of the optic nerve ultimately, upon their arrival in the brain, excite in consciousness what we know as *visual sensations.* The sensations which we get from the retina are therefore primarily sensations of color.

15. Visual judgments. But when we look at an object we get more than mere sensations of color. The world does not appear to us as a flat surface, of different colors, like the painter's canvas. When we look at the wall of a room we know that it is a flat surface, and when we look at a box we know that it has not only length and breadth but also thickness. If we were dependent entirely upon the retinal image for our idea of the box, it would look as flat as the wall; that it does not appear so is because we receive other information about the box than that which comes from the retina. We have to accommodate the lens differently for the near and the far edges, and we have learned by experience that this necessity indicates depth, or different distances of different parts of the object. Again, we see the box with both eyes, and the images formed on the two retinas are not exactly the same. One eye sees more of one side, the other eye more of another side; and while we are not conscious of this fact, we have really learned by experience and by the actual handling of objects that this slight difference in

[1] In this and the following paragraphs white, black, and gray are regarded as colors.

sensations from the two eyes are produced only by solid objects. Again, when we look at any point on the near edge of a box the two eyes are converged by their muscles to a greater extent than when we look at a point on the far edge, and we have learned that these different pulls of muscles and positions of eyeballs indicate that the object is not flat, but has depth. The importance of binocular vision in the estimation of depth or distance from the eye is most strikingly illustrated by attempting, with one eye closed, to bring together the points of two pencils held in the hands and moved from side to side at arm's length.

Consequently when we look at anything we get a number of sensations; from the retina, those of color and the position of the color spots with reference to one another; from the muscular efforts of accommodation and of convergence of the eyeballs, those which reveal the property of depth in what we see. And from all of these, fused together and interpreted in the light of experience, we construct a *visual judgment* of the nature of the object.

Fig. 99

16. Optical illusions. That our vision is essentially the result of unconscious judgments is strikingly shown by the fact that these sometimes deceive us. Thus the parallel vertical lines in Fig. 99, when crossed by the oblique lines, seem to be inclined toward each other. The retinal images of the lines are parallel, and we falsely judge them inclined, this error of judgment arising from the presence of the oblique lines. In other words, our final idea of the lines does not correspond to their image on the retina.

Many other examples might be given showing that our visual idea of the world around us is not a simple sensation or impression, but an unconscious inference, judgment, or conclusion built up from a number of simple sensations taken separately or blended together and compounded with results of lifelong experience. In looking at a piece of fine silk or cloth we seldom stop to think that its tissue may be resolved into many simple component threads; and in quite the same way we fail to realize that even our quickly formed judgments of the size, distance, form, or color of objects are likewise tissues woven out of many threads, most of which we have been slowly and laboriously spinning since childhood's days in the hidden factory of individual experience.

17. Sound and hearing. When the string of a violin, piano, or harp "sounds," one can observe that it is in rapid vibration; and the same thing is true of all sounding bodies. These vibrations are imparted to the air, water, or other surrounding medium, and through this medium they are transmitted as waves of sound. It is these waves, or vibrations, which, on entering the ear, excite the sensation of sound. The more rapid the vibrations, the higher is the pitch of the note; and the greater their amplitude, the louder the sound.

The ear is an organ specially adapted to receive these vibrations of air and to transform them into nervous impulses. It is subdivided by anatomists into the outer ear, the middle ear, and the inner ear.

18. The outer ear. The outer ear consists of the expanded *pinna* (or that part which we commonly call "the ear") and a tube along which the vibrations of sound pass inward to the *tympanic membrane*, or drum. Glands along this canal secrete wax which guards the approach to the drum. It is a bad habit to pick at this wax, and especially to dig into the ear with any pointed instrument, for there is always danger of perforating the drum. If trouble is suspected, a physician should be consulted.

19. The middle ear; the Eustachian tube. The tympanic membrane separates the outer from the middle ear, or *tympanum*, a small cavity lying in the temporal bone of the skull and communicating with the throat or pharynx by means of the Eustachian tube. The air which it contains is consequently under the same pressure as that of the

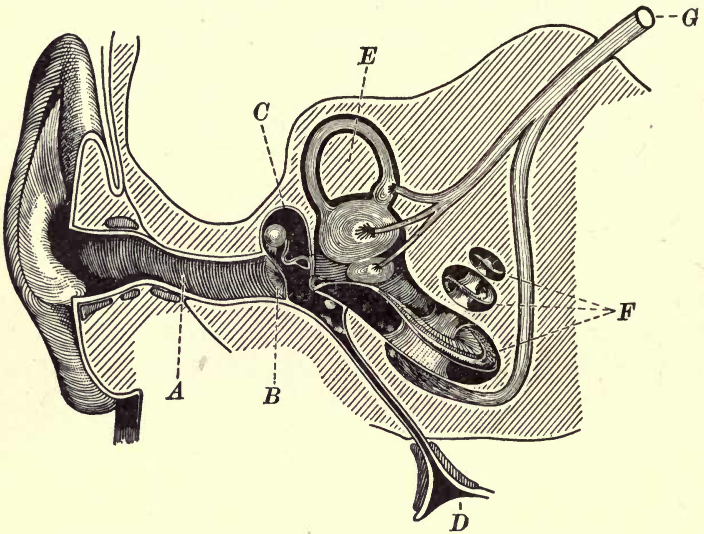


Fig. 100. Diagram of the ear

A, the auditory canal, leading to the tympanic membrane *B*; *C*, cavity of the tympanum, communicating by the Eustachian tube with the pharynx *D*; *E*, semicircular canals; *F*, cochlea; *G*, auditory nerve

atmosphere without, and the tympanic membrane is not normally bulged inward or outward by inequality of pressure on its two sides. The opening of the Eustachian tube into the pharynx is, however, closed except when one swallows, and hence swallowing often relieves the drum from undue pressure of air in the middle ear.

The cavity of the tympanum also communicates with a network of spaces, or *sinuses*, in the temporal bone. Because of these connections of the middle ear with the throat, on the one hand, and with the temporal sinuses on the other, inflammatory processes in the nose and throat during a cold sometimes extend into the Eustachian tube, the tympanum, and even into the temporal sinuses, causing serious trouble and occasionally deafness.

Passing directly across the tympanum, from the drum on its outer side to the cochlea on its inner side, is a chain of three very small bones, the *ear ossicles* (hammer, anvil, and stirrup). These bones are bound together and attached to the walls of the tympanum by ligaments, and are so arranged that when sound waves set the tympanic membrane in vibration this motion is transmitted by the ossicles to a portion of the inner ear known as the *cochlea.*

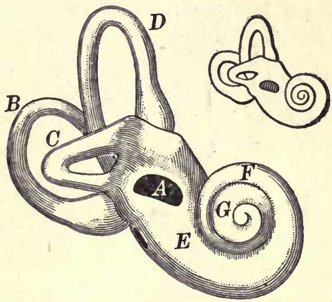


FIG. 101. The bony labyrinth, its actual size being shown in the smaller figure

B, *C*, *D*, the semicircular canals; *A*, the oval window, by means of which the vibrations of the stirrup bone are transmitted to the cochlea; *E*, *F*, *G*, the whorls of the cochlea. Cf. Fig. 102

20. The inner ear. The structures of the inner ear lie in the temporal bone, on the side of the tympanum opposite the drum. They consist of a system of small bony spaces and tubes, the *bony labyrinth*, within which lies a corresponding *membranous labyrinth.* Forming part of the lining of the membranous labyrinth are very sensitive cells, and between these cells are the endings of the nerve fibers which connect the ear with the brain. The cells of the inner ear are sensitive to the vibrations which have been transmitted across the tympanum by the ossicles, just as the retina is sensitive to light; and as the retina is the origin of the fibers of the optic nerve, so the inner ear is the origin of those of the auditory nerve.

21. Taste and smell. The end organs of taste are small rounded eminences, or *papillæ*, on the dorsal surface of the tongue, and from these the fibers of the nerves of taste pass to the brain. The end organs of the nerve of smell are situated in the upper portion of the nasal cavity and consist of delicate cells very sensitive to the presence of odors. Sensations of taste are frequently confounded with those of smell. An onion, for example, has little or no taste, as can be shown by placing a bit on the tongue when one is holding the breath; none of the flavor of the onion is perceived. On the other hand, *sour*, *sweet*, *bitter*, and *salt* are true sensations of taste. This unconscious blending of tastes with odors in forming our ideas of the nature of objects recalls the formation of visual judgments by the combination of retinal sensations with those aroused by the muscular act of converging the eyeballs.

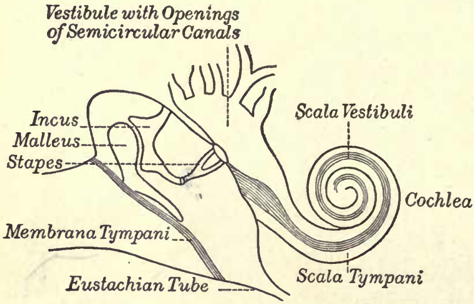


FIG. 102. Diagrammatic representation of the membranous labyrinth of the cochlea in relation to the structures shown in Figs. 100 and 101

The *scala vestibuli* and *scala tympani* are the two portions of the bony cochlea which inclose the membranous cochlea

22. Cutaneous sensations. The skin is the place of origin of at least three sensations — touch, cold, and warmth. These sensations are distinct, as is shown by the observation that on certain points of the skin some of them may be felt, but not others. This fact is usually interpreted to mean that each sensation has its own set of end organs and nerve fibers. Especially striking is the fact that warmth and cold are not felt by the same spot of skin, which seems to prove conclusively that they are separate sensations.

The afferent nerves of cold and warmth not only carry into the brain those impulses which give rise to the corresponding sensations but also serve as one important means of stimulating the reflexes which help to regulate heat production and heat output (see Chap. XII).

23. The sense of position. The expression "the five senses" has become proverbial, and comes from the time when sight, hearing, taste, smell, and touch were the recognized special senses. To-day, however, we must add to these not only warmth and cold but still others, most conspicuous among which is the sense of position. When the eyes are closed we are aware of the position of the various parts of the body. We know whether the arm is bent at the elbow or straight; whether the head is looking forward or is turned to one side or the other. And while we are aware of these things, partly from tactile sensations, there is conclusive evidence that afferent impulses from the muscles, tendons, and joints also play an important part in the result.

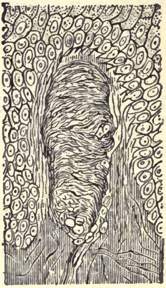


FIG. 103. A tactile corpuscle in one of the papillæ of the dermis; an end organ of the sense of touch

When one is blindfolded and lies flat on a revolving table which can be turned noiselessly in one direction or the other, the subject of experiment can form fairly correct judgments as to the angle and direction through which the table is turned. Here there is no change of character either in the tactile impulses or in those from the muscles, tendons, and joints, for the subject of experiment lies still and is only passively moved. It is believed that in this case the sensations in question come from the movements of the lymph in portions of the inner ear. One part of this, the cochlea, is undoubtedly concerned with the perception of sound; but another part, the three *semicircular canals*, are now believed to be end organs of this sense of position.

The impulses which make us aware of the position of parts of our bodies also play a very important rôle in reflexly guiding our movements. Upon this we shall dwell at greater length in subsequent chapters (see especially Chap. XV).

24. Sensations of pain. Most organs of the body may also give rise to impulses which, on their arrival in the brain, cause sensations of pain. It is still, perhaps, an open question whether this sensation, like sight, smell, and hearing, is aroused by its own mechanism of end organs and afferent nerves or whether it is called forth by the excessive stimulation of the nerves of the other senses, but for the discussion of this question the reader must consult more advanced works on physiology.

Pain is a useful danger signal, since it effectively calls attention to abnormal conditions and incites us to the adoption of active remedial measures. Remedies, however, should not be confined to the abolition of unpleasant sensations, but should be directed to the removal of their cause. A toothache from a decaying tooth may often be stopped, for a time at least, by the use of chloroform or other anesthetic drugs, but the drug only stops the pain; it does not check the progress of decay or repair the damage. Again, a bronchial cough may be unpleasant and even painful, but we should not rest content with the use of some drug or cough medicine which merely lessens the irritability of the inflamed surface of the air passages, and so, perhaps, stops the cough without curing the disease.

Pain is a warning that some abnormal condition needs attention. Sometimes that attention may be supplied by the sufferer himself, or by his friends, but often skilled medical advice is needed. Too frequently, for the sake of economy or from feelings of modesty, or even because of an unwillingness to acknowledge illness either to the world or to one's self, the mistake is made of postponing the visit to the physician, the patient meanwhile bearing discomfort and perhaps actual suffering in the hope that he will soon be better and that the trouble will "cure itself." Sometimes, of course, it does cure itself; but sometimes it does not; and remediable disease has too frequently been allowed to run on in this way until some vital spot is attacked or the trouble has become too grave for medical skill to overcome. Many diseases, like a fire, may be extinguished at the start, but if not attended to, grow rapidly into a conflagration beyond control. Pain is one of the most trustworthy warnings that attention to the mechanism itself or to our operation of it is necessary; and we have no right, either for our own sake or that of our friends, to neglect its warnings. While there are times when it is an act of heroism to endure suffering and to keep the knowledge of it to one's self, there are other times when to do this is not only foolish but wrong.

25. Hunger and thirst. No account of the physiology of sensations would be complete without some reference to those very common experiences of life — hunger and thirst. We have already spoken of them as sensations which are referred to the body and never to external objects, thirst usually being referred to the mouth and throat, and hunger frequently to the stomach; but hunger and even thirst may sometimes affect us as sensations coming from the body as a whole, in which case they are usually indistinguishable from certain forms of general fatigue.

Hunger is excited by automatic rhythmic contractions of the musculature of the cardiac end of the stomach. The stomach, like the heart, executes rhythmic contractions, and we may speak of the "beat" of the stomach just as we speak of the "beat" of the heart, although each stomach contraction is much slower than those of the heart. When food is in the stomach, these contractions or "beats" are inhibited in the cardiac end or else are reduced to very insignificant proportions, and we have the inactive condition of this portion of the stomach described in Chapter VIII;

but when the cardiac pouch is again empty, the inhibiting check is removed and the automatic "beats" become quite powerful. These contractions start impulses up the sensory nerves of the stomach, and these impulses excite in our consciousness sensations of hunger. Often the "beats" occur in rhythmic periods, a group of strong contractions alternating with groups of weak contractions or even total quiescence. In this case we have the "griping" hunger pangs coincident with the strong contractions. In certain abnormal conditions the presence of food in the stomach fails to exert its inhibiting effect and we have a continual "gnawing" hunger.

Thirst is aroused by the dryness of the mouth and throat, probably by the reduction of the amount of water in cells and tissues of this organ.

Hunger and thirst are definite sensations, as truly adapted to guide us in the choice of food as sight is adapted to picture to us the world in which we live. So long as the body is normally occupied and healthy they may usually be trusted; but there are abnormal conditions of sedentary life, in the midst of a superabundance of tempting food, when they become less trustworthy, and in some forms of dyspepsia the sensation of hunger is never absent, no matter how often one eats. In such cases the very effort to satisfy hunger only aggravates disease. Conditions of this sort should not prevail if proper attention be paid to the general hygienic conduct of life. Broadly speaking, appetites, like fire and dynamite, are good servants but bad masters.

CHAPTER XV

THE NERVOUS SYSTEM

A. Its Anatomical Basis

In the preceding chapter we have repeatedly emphasized the fact that sensations of all kinds are developed in the brain from nervous impulses coming from the sense organs, and in a previous chapter (VII) we have seen that without reaching the brain, or at least without affecting consciousness, these afferent impulses may give rise to reflex action. A reflex action or a conscious sensation, or both a reflex action and a conscious sensation, may therefore result from the entrance of a nervous impulse into the central nervous system, and we have now to inquire what is known of the mechanism by which these results are brought about.

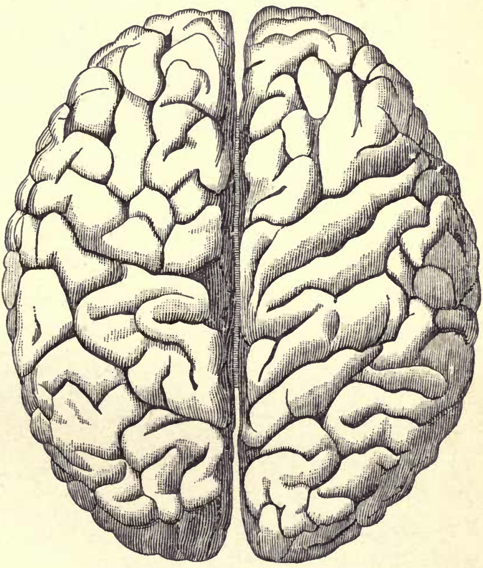


Fig. 104. The human brain viewed from above. The cerebral hemispheres completely cover the rest of the brain

1. Fundamental structure of the nervous system; the brain of a frog. The human spinal cord and brain are so complicated that it is best to study first the nervous system of a simple vertebrate like the frog, for the fundamental plan of structure is the same in both. The spinal cord is a relatively thick-walled tube, the walls of which are composed of white and gray matter, the minute bore, or lumen, of the tube being known as the *central canal.* The arrangement in the brain is similar, but here the central space is no longer a small tube of even bore, but consists for the greater part of irregular cavities known as the *ventricles* of the brain, while the walls consist of masses of gray and white matter varying in size, shape, and relation to each other.

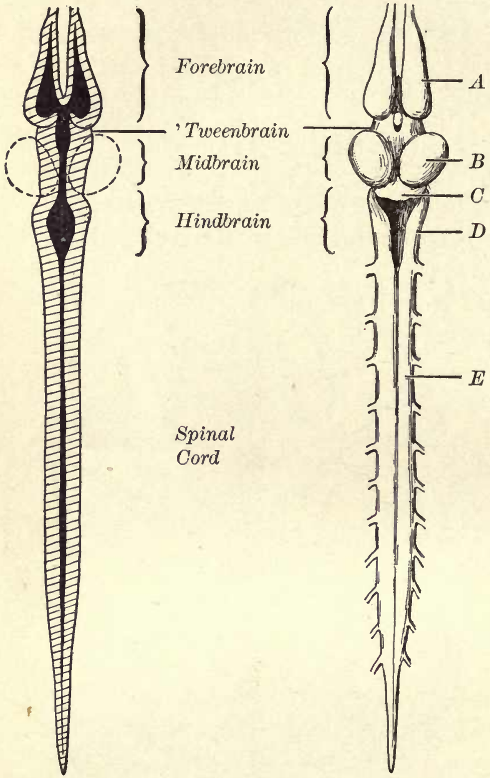


Fig. 105. The brain and spinal cord of the frog

On the left is a longitudinal, right-to-left section, showing the central canal and the ventricles of the brain; on the right the dorsal view of the brain and cord. *A*, the cerebral hemispheres; *B*, the optic lobes; *C*, the cerebellum; *D*, the bulb; *E*, the spinal cord

Fig. 105 will assist the student in understanding this plan of structure. Anteriorly the spinal cord is continued in the *bulb*,[1] whose central cavity is the fourth ventricle. Part of the dorsal wall of this ventricle forms the *cerebellum*, which in the frog is only slightly developed, but which in higher vertebrates (birds and mammals) becomes a large and conspicuous organ. Anteriorly the fourth ventricle is connected with the third by a tube, the *aqueduct of Sylvius*. The thick walls of this aqueduct contain various masses of gray matter whose names need not detain us; the walls of the *third ventricle* are similarly composed of large masses of gray matter

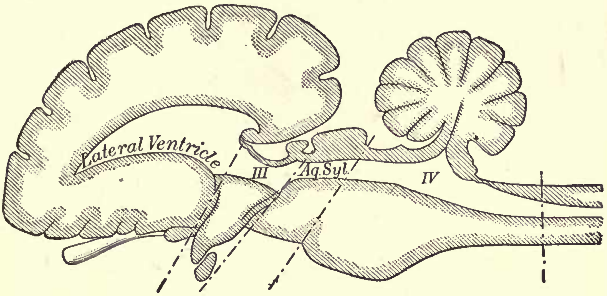


FIG. 106. Diagrammatic median longitudinal section of a mammalian brain
After Edinger

For convenience the cerebrum, with its lateral ventricle, is represented as a single organ in the median plane instead of two hemispheres on either side of this plane and each with its own lateral ventricle. The division into forebrain, 'tweenbrain, midbrain, and hindbrain is marked by the broken lines

scattered among the fibers of the white matter. Still farther forward two openings from the third ventricle, one on the right and one on the left side, lead into the large *lateral ventricles*, the nervous tissue of whose walls is the *cerebrum*, or the *cerebral hemispheres*. It is convenient to divide the brain into the forebrain, surrounding the lateral ventricles; the 'tweenbrain, surrounding the third ventricle; the midbrain, surrounding the aqueduct of Sylvius; and the hindbrain, surrounding the fourth ventricle.

[1] The older term for the bulb is the *medulla oblongata*, to distinguish it from the *medulla spinalis*, or spinal cord.

2. The brain of the mammal is built on the same fundamental plan as that of the frog, and differs from it mainly in the greater number of neurones and in the complexity

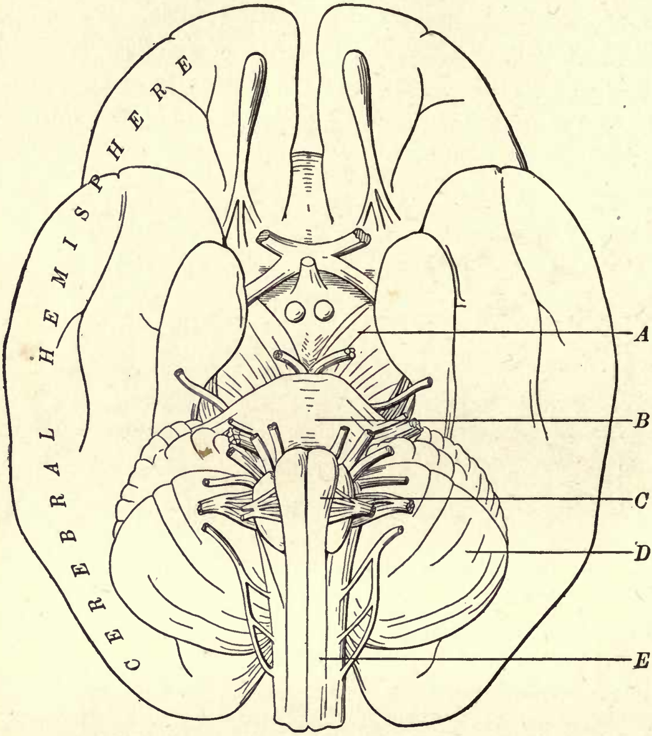


FIG. 107. The base of the human brain, showing the cranial nerves

A, the *crus cerebri*, composed largely of nerve fibers which connect the hindbrain with the 'tweenbrain and forebrain; *B*, the *pons Varolii*, the anterior floor of the fourth ventricle, connected laterally with the cerebellum; *C*, the bulb; *D*, the cerebellum; *E*, the spinal cord

of their connections with one another. This results in great thickening of the ventricular walls and the formation of a very complicated anatomical structure. Mammals are especially characterized by an enormous development of the cerebral hemispheres, which in man grow to such proportions upwards and backwards as to overhang and completely cover the other structures on the dorsal side. But even these large masses of nervous tissue, no less than the smaller cerebrum of the frog, are composed entirely of the gray and white matter forming the walls of the lateral ventricles.

By comparing the brain of a frog (Fig. 105) with those of the rabbit, cat, and monkey (Fig. 166), and finally with

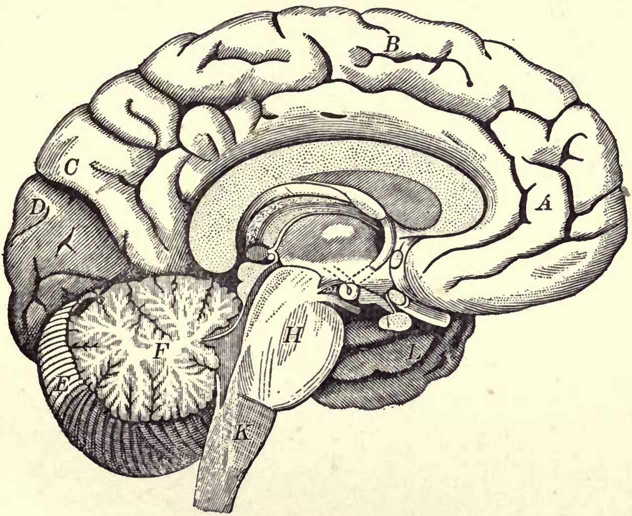


Fig. 108. Median longitudinal section of the human brain

A, *B*, *C*, *D*, *L*, convolutions of the median surface of the cerebrum; *E*, *F*, the cerebellum, showing in the plane of section the inner white matter and the outer gray matter; *H*, the *pons Varolii*; *K*, the bulb

the human brain (Figs. 104, 107, 108), a fairly good idea may be had of the increasing complexity of the brain as we pass from the lower to the higher animals. Especially noteworthy is the greater relative prominence of the cerebrum. In the frog this organ is small and inconspicuous; in the rabbit it is much larger, but its surface is smooth; in the cat there is a further increase in size, and the surface is thrown into folds, or *convolutions*; and this increase in size and surface folding — carried yet farther in the monkey — reaches its highest development in the human brain.

Fig. 109. A portion of the gray matter (cortex) of the cerebrum (highly magnified). After Kölliker

Note the large number of dendrites. The axons are the fibers of uniform diameter running lengthwise of the drawing. One of these cells is shown in Fig. 41, *D*

3. The cranial nerves. Nerves enter the 'tweenbrain, midbrain, and hindbrain somewhat as they enter the spinal cord; and although their separation into dorsal and ventral roots is not obvious, the neurones to which their nerve fibers belong are in all respects analogous to the neurones of the spinal nerves. They may serve as the paths of reflexes (for example, a wink is a reflex from the optic or the trigeminal nerve to the facial nerve), and their relation to the cells of the cerebrum and other higher portions of the brain is essentially the same as that of the spinal nerves. Fig. 107 will give the points of entrance or exit of these nerves from the human brain.

4. Histological structure of the brain. Microscopic study of the brain shows an aggregation of neurones similar to that seen in the spinal cord. These neurones differ greatly in shape (see Chap. VII, p. 73), in the number of their dendrites, and in the abundance of their connections with other neurones. The regular arrangement in the cord of central gray matter surrounded by white matter is wanting; instead, masses of gray matter occur here and there among the bundles of nerve fibers of which the white matter is composed. In the cerebrum and cerebellum the external surface consists of gray matter and is known as the *cortex* of the cerebrum and cerebellum respectively. These cortical structures form the most complicated system of nervous tissue in the body, and the cerebral cortex is intimately concerned with the highest functions of the brain. (See Figs. 109, 110, and 111.)

The figures give some idea of the variety and complexity of the neurones of the brain. But however different, at first sight, the brain may be from the spinal cord, the anatomical plan of organization is the same in both; the brain as well as the cord does its work because the connections of its neurones with one another bring about coördinated action. The secret of the structure of the brain, as of the cord, lies in the nature of the connections of its units, the neurones, one with another.

B. The Physiology of the Nervous System

Whenever through accident, disease, or otherwise, some portion of the nervous system is destroyed, functions dependent upon it are no longer performed, or at least are not performed normally. A very large number of observations have been made upon both animals and men in this condition, and these have made it possible for us to obtain some idea of the part played in normal life by each part of the brain and cord. We shall attempt here to sketch only a few of the more important outlines of the picture, which the reader may complete by more extensive study of physiology and psychology.

We shall choose for study the case of a single animal, the frog, the anatomical structure of whose brain has been given in this chapter. The phenomena shown by the frog are, however, as far as we shall describe them, in general true of higher vertebrate animals.

We shall therefore study (1) the behavior of a frog whose brain has been destroyed, that is, a frog which possesses no part of its central nervous system except the spinal cord; (2) the behavior of a frog with spinal cord and bulb intact, but destitute of midbrain, 'tweenbrain, and cerebrum; (3) the behavior of a frog with spinal cord, bulb, midbrain, and 'tweenbrain, but destitute of the cerebrum.

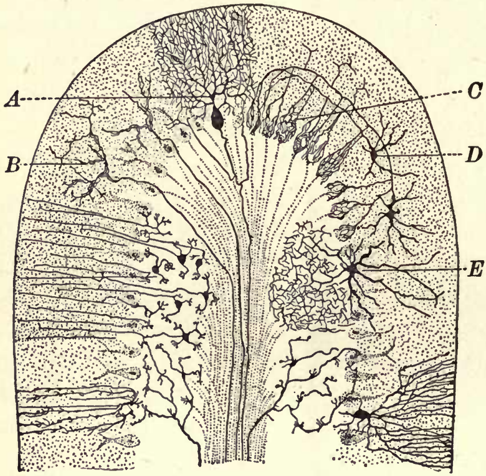


FIG. 110. Transverse section of a convolution of the cerebellum. After Ramon y Cajal

The figure represents only a few of each kind of nerve cells and nerve endings. *A*, *D*, *E*, cells; *B*, *C*, nerve endings (synapses)

The behavior of these incomplete animals will each be compared with that of a normal frog, which, of course, possesses a complete nervous system.

5. The behavior of a brainless frog; that is, a frog which possesses of its nervous system only the spinal cord. Such a frog can carry out only reflex actions of a comparatively simple character. It lies flat upon its belly and, like the normal frog, bends its hind legs under its flank, but does not sit erect by supporting the head and upper trunk on the fore legs. There are no respiratory movements; the vaso-constrictor tone of the blood vessels is impaired or absent, as are also many other of the most important reflexes.

But if one leg be pulled gently backward, the animal will bend it again to its normal position under the body. If the toe be pinched, the leg will suddenly be drawn away; and if the skin of the flank be irritated by a bit of filter paper moistened with acid, the paper will be kicked off by the leg of the same side.

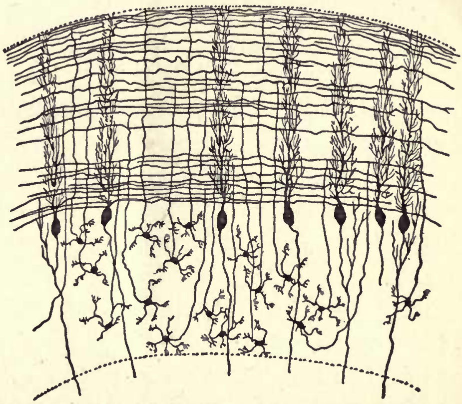


FIG. 111. Section of the cortex of the cerebellum (at right angles to that shown in Fig. 110). After Ramon y Cajal

These are all purposeful[1] and coördinated actions, and make upon the inexperienced observer the impression that the frog is aware of the stimulus and acts intelligently. But the mere fact that an act is purposeful and coördinated does not show that it is a conscious act; our movements of respiration, winking, coughing, and sneezing are purposeful and coördinated, but we know well enough that they, as well as more complicated actions, may and often do occur in the complete absence of consciousness. One of the first lessons that the student of animal behavior must learn is not to make the mistake of regarding an action as conscious merely because "it looks so" or is purposeful and more or less highly coördinated.

[1] The word "purposeful" is used here in the same sense as in Chapter VII (p. 70) and does not include conscious purpose in its meaning. We shall see that conscious purpose involves the coöperation of the cerebrum.

The spinal cord alone, then, and without the help of the brain, is capable of maintaining a small part of the normal posture of the resting frog and also of executing some of the simple reflexes, especially those involving movements of the hind legs, but it does not seem to be capable of originating actions or of doing any except reflex actions.

6. The behavior of a frog with spinal cord and bulb only. In this case there is no new feature in the maintenance of posture; the frog lies on its belly and executes the same reflexes as before. The respiratory movements, however, go on in a normal manner; the vasomotor tone of the arteries is maintained, most vasomotor reflexes may be produced with ease, and the heart may be reflexly inhibited. As compared with the brainless frog, the number of actions which the animal can execute is increased, and the reflex movements become somewhat more complicated; but the differences are slight as compared with those seen in the animal which has the 'tweenbrain and midbrain in addition to the hindbrain and cord.

7. The behavior of a frog with spinal cord, bulb, midbrain, and 'tweenbrain; that is to say, a frog with the entire nervous system exclusive of the forebrain, or cerebrum. The following points are especially noteworthy: (1) the sitting posture maintained at rest; (2) balancing movements; and (3) more complicated movements of locomotion.

(1) Such a frog, unlike those already described, *sits erect* exactly like a normal frog; and this fact shows that complete maintenance of the normal posture requires the coöperation of higher portions of the nervous system than the bulb and spinal cord, but does not involve the coöperation of the cerebrum.

(2) If the frog be placed on a rectangular block of wood, and the block slowly turned so that the frog tends to slip off backwards, it will crawl up and over the descending edge, keeping itself perfectly balanced. By continuing to

turn the block the frog can be made to creep around it almost indefinitely. Thus it not only maintains the erect position but also *corrects loss of equilibrium* by appropriate balancing movements.

(3) If the frog be stroked upon its belly, it will croak; if its lips be touched with a blunt pin, it will brush the pin away with its forefoot. Most important of all, if it be thrown into the water, it will swim; and when it reaches a solid object it will crawl out upon it and come to rest. In short, the animal will carry out almost any movement of which a normal frog is capable, *provided the proper stimulus is applied*; but without this it will do nothing, though capable of doing so much.

The facts thus far brought forward show that the neurones of the 'tween, mid, and hind brains and of the spinal cord constitute nervous mechanisms which can maintain the normal posture, correct loss of balance, and even carry out the usual acts of locomotion. The more of the nervous system which the animal retains, the more complicated are the movements, as we should expect when we remember the increase in the number of neurones and the greater complexity of coördination thereby rendered possible.

8. Comparison with the normal frog. The behavior of a frog lacking only the forebrain, or cerebrum, differs from that of a normal frog in two most significant respects. In the first place, the animal rarely makes any movement without obvious external stimulation; if protected from drying, it will often sit motionless for days, or even weeks. Such is not the conduct of an animal which is aware of what is going on around it or of its own sensations or feelings, that is, of a conscious animal. In the second place, the frog shows the most remarkable regularity and persistency in making repeatedly the same response to the same stimulus; if its lips be touched thirty times with a blunt needle, it will brush at the offending object every time in the same way with the same forefoot. We should certainly not expect a conscious animal to do this; for, after trying one plan of action a few times, it would realize that its efforts were unavailing, and would try something else, such as jumping away. This same peculiarity is met with in all animals deprived of the cerebrum. They act like mere complicated and faithful machines; they do not act as if they were thoughtful, original, or wise.

Especially striking is the avoidance of objects during locomotion. This fact looks at first sight as if the animal were aware of the presence of the obstacle in its path; but a dog without a cerebrum, even when it has been without food for a day or more, will go to one side of a piece of meat and pass it by. He acts as if *unaware of the nature of the object*, of its use as food, etc. The image of the piece of meat formed on his retina seems to generate nervous impulses which pass to the brain by way of the optic nerve and reflexly guide the movements of the dog, but these impulses do not inform the animal of the nature of the object, and we have no reason to believe that the dog is aware of the existence of the meat.

When we consider our own experience we find that we too, as we walk along a crowded street, avoid objects, not only without noticing them but without even being aware of their presence. Here again the afferent impulses from the retina pass to the nervous system and *reflexly* guide our walking without affecting consciousness at all. And the wonderful feats of somnambulism, where the "eyes are open" but "their sense is shut," where the sleeper maintains his balance and avoids stumbling in situations where he would almost inevitably fall if he were aware of his surroundings, show how perfect is this very complicated mechanism of locomotion, which seems to be complete even in the absence of the cerebrum.

We are, indeed, so accustomed to regard our actions as volitional and conscious that we rarely consider the large part which reflexes from the eye, the ear, the skin, the muscles, and the joints play in guiding them. We will to do a certain thing, to walk to a certain point, for example; perhaps the first step is a volitional act, but subsequent steps, the suiting of these steps to slight unevenness of the path, the avoidance of many obstacles, the maintenance of the balance of the body as a whole, — for we walk not only with the legs but with the entire body, — all these things take place apart from any exercise of the will and, for the greater part, in the entire absence of consciousness, although consciousness may, of course, at any time intervene. Reflex actions thus play a most important part even in the execution of those movements which we think of as distinctly conscious acts.

9. Connections of the cerebrum with lower portions of the nervous system; "the way out." Granting that the nervous events at the basis of consciousness occur within the cerebrum, how do these events influence the muscles, the glands, and other organs which do the bidding of the will? What is the way out from this seat of consciousness? This path has already been referred to in Chapter VII (p. 81). Cells in the gray matter of the cerebrum give off axons which pass downward through the structures of the 'tween, mid, and hind brain into the white matter of the spinal cord. These axons give off along their course collaterals which end in arborizations around nerve cells of the lower portions of the nervous system and, by bringing groups of these cells into coördinated activity, produce definite volitional movements. The student should review carefully in this connection what has already been said with reference to these neurones (see Fig. 165, *v*).

10. Connections of the cerebrum with lower portions of the nervous system; "the way in." The fact that afferent impulses from our sense organs of sight, hearing, etc. may affect consciousness indicates that there must be some connection between afferent neurones and the cerebral hemispheres, since only when the latter are present does a nervous impulse produce a conscious sensation. The connection is not, however, so direct as in the case of efferent impulses. The neurone of the dorsal root may be traced as far as the bulb, but no farther; from this point the impulse can find its way to the cerebrum only by new neurones, and of these it would seem that there are several. These relations are indicated in Fig. 165, where the efferent neurones are represented in black, and the afferent in red.

This diagram brings out the fact of increasing complexity of reflexes as we proceed to the more anterior portions of the nervous system. In the spinal cord the collaterals of the afferent neurone act upon the efferent neurones; in the structures of the midbrain and the 'tweenbrain the afferent tract makes connection with more and more complicated and extensive systems of these efferent neurones or motor mechanisms. The range of possible movement is increased to include most of the usual actions of the animal, and some of these actions represent a very high degree of coördination. Finally, in the cerebrum the highest of all these connections is made; here take place those events of whose nature we have thus far been quite unable to form any conception, but which play some part in the genesis of conscious sensations and in the closely related dispatch of volitional impulses. We can now understand why it is that removing this highest portion of the nervous system leaves untouched not only the simpler reflexes but even the more complicated reflexes of locomotion, of swimming, of flight, etc.

11. The nervous factors in locomotion; automatic and reflex elements. It is clear from the considerations given above that walking, running, and other forms of locomotion are essentially nonvolitional acts, and it is also clear that there must be a nervous mechanism capable of carrying them out without the aid of and in the complete absence of consciousness. What is the nature of this mechanism? In answer to this question we can only make a suggestion without pretending to give a final explanation.

In the first place, walking obviously involves alternate steps, or forward thrusts of the body by the two legs; that is, while one leg is pushing the body forward by straightening at hip, knee, and ankle joints, the other leg is bending at these joints, the flexion of each leg at the hip joint bringing it forward in preparation for its next forward thrust. In each leg, then, we have an alternation of "forward swing" (flexion at hip, knee, and ankle) and of "extensor thrust" (extension at hip, knee, and ankle). In the same leg the flexors of the hip, knee, and ankle obviously contract at approximately the same time, and the extensors at the three joints similarly act together; furthermore, the extensor action in one leg is simultaneous with the flexor action in the opposite leg. These actions may be represented in diagram as follows:

Right leg	Hip	Ex.	Fl.	Ex.	Fl.
	Knee	Ex.	Fl.	Ex.	Fl.
	Ankle	Ex.	Fl.	Ex.	Fl.
	Toes[1]	Fl.	Ex.	Fl.	Ex.
Left leg	Hip	Fl.	Ex.	Fl.	Ex.
	Knee	Fl.	Ex.	Fl.	Ex.
	Ankle	Fl.	Ex.	Fl.	Ex.
	Toes	Ex.	Fl.	Ex.	Fl.

Vertical columns represent simultaneous actions at the eight joints

Now it has been shown that in an animal made unconscious by ether anesthesia, and in which no afferent impulses may enter the cord or brain, — because of the depth of anesthesia or even because of cutting the dorsal nerve roots, — similar movements of the hind legs spontaneously arise and may

[1] Flexion of the toes in each leg occurs simultaneously with extension at the other three joints, and vice versa. With most people, owing to the use of improperly shaped shoes, the toes are little used in walking. See Chapter XXIV on the Hygiene of the Feet.

be kept up for long periods of time. Evidently there is *a mechanism consisting entirely of motor or efferent neurones* which by itself, independently of any afferent (that is, reflex) or volitional stimulation, *can automatically carry out a large part of the act of locomotion.* Locomotion becomes fundamentally the act of an automatic mechanism and is comparable to the alternate automatic contractions of inspiration and expiration.

The parallel between the automatism of respiration and the automatism of locomotion becomes still more striking when we find in both cases that afferent impulses do actually intervene to guide and so make more exact and efficient the fundamental automatic movements. Thus we know that afferent impulses started by the expansion of the lungs during inspiration check the inspiratory effort then in progress and so bring on the next expiration sooner than it would automatically occur. Similarly, the pressure upon the sole of the foot as it touches the ground reflexly guides and probably strengthens the automatic extensor thrust; and many other reflexes through the cord are known to serve similar functions.

To sum up, then: The action of the legs in locomotion seems to be fundamentally an automatic action, but these automatic movements are guided by afferent impulses which stream in from skin, muscles, and joints as the act progresses. Just as we can volitionally hold the breath, so we can volitionally start or stop walking; or just as we can volitionally change the depth and rhythm of respiration, so we can volitionally change the pace or length of stride; or just as a dash of cold water on the skin or the presence of an irrespirable gas reflexly changes the character of the breathing movements, so unevenness of the path or visual impulses from an object in the way changes the character of the locomotion. In all cases reflex and volitional interference acts on a fundamental automatic nervous mechanism.

12. The maintenance of balance and the regulation of muscular tone. Walking, however, involves more than the action of the neuromuscular mechanisms of the legs; for here, as well as in complicated volitional actions, the balance of the body must be preserved. For this reason we swing the arms and execute ever-changing contractions of the muscles of the trunk. Moreover, a proper state of tonic contraction in each muscle is necessary to the proper execution not only of the act of walking but of other acts as well, whether these are volitional or nonvolitional. Into the mechanism of this wonderfully perfect function of the body we cannot go within the limits of the present book; but there is good ground for thinking that, at least in the mammals, the cerebellum is a very important and probably the all-important organ concerned in effecting these coördinations.

13. Actions resulting from nervous processes originating within the cerebrum. A very large part of the activities of the body are thus fundamentally reflex actions; they do not require the aid of consciousness for their execution. And it is fortunate for us that this is the case; one has only to imagine a human being who has to give his attention, or "his mind," as we often say, to every adjustment of the digestive, respiratory, and vascular systems required to meet the changing necessities of life; who has to keep his thoughts on every movement of walking or running; who has to be constantly on guard against loss of balance even when sitting still. Such a being is almost inconceivable; he would "go crazy" in a single day; but we can in this way realize to what extent the reflex mechanisms of the body perform the menial offices of life, leaving the mind free for higher things.

Speech is the result of movements in which the muscles of respiration, those of the larynx, those of the tongue, and those of the lips coöperate to produce articulate and intelligible sound. The act of writing also consists of a series of movements in which the muscles of the arm and hand coöperate to make thought visible; performing on a musical instrument, modeling a figure in clay or marble or bronze, painting a picture — all these things occur to us as examples of movements which are fundamentally neither reflex nor automatic. Such are the highest actions of the body, and the movements of which these actions are made up are chosen and directed by the will.

These higher actions, like consciousness, depend upon the presence of the forebrain. When a certain area of the cerebrum is destroyed by disease, the power of speech is lost; when another part is destroyed, the skilled use of the hand is lost; destruction of other portions affects in the same way others of these skilled movements. In such cases locomotion, the maintenance of balance, the movements of respiration, etc. may be and usually are unaffected; the patient merely loses the power of doing one or more of those things which involve the selection of disconnected and to some extent independent movements giving expression to some original thought, sentiment, or idea.

The neurones of the cerebrum and their connections thus constitute nervous mechanisms whose activity is essential to consciousness, — to our seeing, our hearing, our smelling, and, more than this, to our understanding of what we see, or hear, or smell, — nervous mechanisms whose activity is also necessary to the expression of our thought in action. It is because of this fact that, when the cerebrum is removed, the animal becomes merely a complicated reflex machine, acting only as it is immediately stimulated from without or by events taking place within its own body.

14. Effects of anesthetics on the nervous system. When a person passes under the influence of an anesthetic, the first function to disappear is consciousness; the ether or the chloroform first paralyzes this highest and most complex connection between the afferent and the efferent sides of the nervous system. In this condition the patient may groan and struggle, for he is in somewhat the same state as the animal without cerebral hemispheres. The use of the surgeon's knife will still produce movements; respiration may be affected so as to result in groans and other movements which the inexpert observer, perhaps in alarm, attributes to severe suffering; and yet when the patient awakes he tells us he knew nothing of what passed and felt no pain. It is important to realize that *the signs of pain are never reliable evidence of its existence.*

If the anesthesia be pushed further, even these more complicated reflexes disappear. In the ordinary major operations of surgery the ether or the chloroform is given until it interrupts not only the cerebral connections between the afferent and efferent paths but also those of the lower portions of the brain; it is even administered until only a few reflexes are left, such as the wink when the cornea is touched, the contraction of the pupil when the eye is exposed to light, etc. — these serving as useful tests of the condition of the patient. If, for example, the pupil no longer contracts to light, it is an indication that the anesthesia is going too far — too near the point where the nervous mechanism of respiration, etc., will be paralyzed. The giving of ether is then suspended until these reflexes are again well established.

After the operation, as the ether or chloroform is eliminated from the system, the reflexes return in the reverse order; and the unconscious movements, groans, incoherent, or even more or less coherent, talking (comparable with talking in one's sleep) are sometimes most harrowing to the feelings of those who do not understand that they are all unconscious acts. The physician and nurse who remain unmoved may even be wrongly charged with lack of feeling because they do not waste sympathy where they know there is neither suffering nor consciousness.

15. Inhibitory phenomena in the nervous system. We have learned that some nerves excite organs to activity, while others diminish activity or abolish it altogether (p. 160). The beat of the heart is quickened by one set of nerves and slowed by another; the circular muscular fibers of the arterioles are excited to contract by vasomotor nerves, their tonic constriction is paralyzed or inhibited by vasodilators, and many other examples might be drawn from the action of neurones on peripheral organs of the body.

Precisely the same thing is true in the brain and spinal cord. Afferent impulses may not only reflexly excite neurones to activity but may also inhibit the existing or threatened activity of other neurones, as when a sneeze is stopped by biting the upper lip or by pinching the nose; or an action may be inhibited by a volitional impulse from the cerebrum, as when the breathing movements are voluntarily stopped for a while, or when we similarly stop a wink or a sneeze. These are all examples of inhibition, not of the skeletal muscles concerned but of the neurones which innervate them — in other words, of the inhibition of one neurone by another.

It must be understood that inhibition is as essential a part of the activity of the nervous system as is excitation. Just as the driver of a team must urge on one horse while he restrains another, so in all more complicated actions, probably in all actions, reflex or volitional, the orderly movement is as much the result of holding one neurone in check as of stimulating another one to work, or to work harder. Consciousness proves its presence most conclusively by suppressing reflexes which would otherwise inevitably occur and by bringing about *new* movements to meet the desired end. Even in the highest processes of the most highly organized of nervous systems, namely, those in which human action originates, the man reveals his character and influences the world around him by what he does not do — by what he refrains from doing, sometimes at the cost of severe struggle against impulse, instinct, or passion — quite as much as by what he does. Education, even, has been partially defined as the "training of inhibitions and the control of reflexes."

16. The cerebrum the chief organ for the acquisition of new coördinations and associations. It would, however, be taking too narrow a view of the functions of the cerebrum to regard it simply as the seat of consciousness and volition. In Chapter VII, § 15, we saw that in addition to definite inherited reflex mechanisms, such as those of winking, — the so-called unconditioned reflexes, — new paths of conduction from the afferent to the efferent side are acquired during life by the repeated association of two acts. Doubtless all parts of the brain and spinal cord possess in some degree this power of making new associations like those concerned in the conditioned reflexes; but the cerebrum is certainly the organ in which they are made most readily, and there can be no doubt that one of its chief functions is the acquisition of such new paths of conduction as the experience and activities of life first blaze within its nervous substance and subsequently, by the repeated passage of nervous impulses over the "blazed trail," change to "beaten paths" of easy conduction. Here every act and experience of life may leave its record, and here good and bad habits are acquired.

17. Use and disuse as factors in individual development, training, and efficiency. When we consider the marvelously complicated character of the nervous mechanisms which control our actions, we naturally wonder how this intricate machinery can be built and why it does not more frequently get out of order. We cannot say that a simple and comprehensive answer will not some day be given to these questions, but to-day we have no adequate answer whatever. The neurones with which we must work in life are born with us; but in most cases efficient connections must subsequently be made between them, thus perfecting the mechanisms they compose; and this perfecting of the nervous machine comes with use. The use of a nervous mechanism is generally essential to its proper development, just as the use of a muscle is essential to its strength. If the child never tried to walk, the neurones which carry out the movements of walking would not develop; not only do the muscles of an arm strapped down to the side of the body waste away and become practically bands of connective tissue, but the neurones concerned in the actions which the arms should execute degenerate and may ultimately be irreparably injured.

Provision is made from earliest life for the proper development of these neurones and the establishment of irritable connections between them by use; out of the first aimless movements of the head and eyes and hands and legs of the baby the simpler coördinating nervous mechanisms are one by one brought to perfection; then comes the training of those reflexes which maintain the erect position and of those nervous mechanisms which govern locomotion; then *play* comes in, with its ceaseless activity, increasing still further the number of movements which the nervous system can make and correspondingly enlarging the possibility of human achievement. As the child grows older the family calls upon him to contribute some share to its life or support; new activities, in the shape of chores about the house or the farm, now share with play the work of the nervous system; activity becomes less general, more special. Finally the youth settles down to some definite occupation or pursuit, and the more strictly this is adhered to, the narrower becomes the range of activity; the more constantly a few systems of neurones are used, the more rarely are others called into play.

18. The physical basis of habits. All this indelibly writes its history in the nervous system. No fact is more significant or of greater physical and moral import than that the doing of any act so affects the connections of neurones with one another as to make it easier to do the same act again under the same conditions; that refraining from doing something toward which we are inclined similarly renders more easy the inhibitory processes concerned when the same conditions impel us toward it again. We are largely what we make ourselves by the training which our actions give to the nervous system.

And what activity thus does for the *development* of power it does also for the *maintenance* of power. An efficient nervous mechanism of any kind once acquired does not remain efficient without use. The man who has developed a rugged constitution in colder climates and then lives for years in the tropics, constantly exposed to a warm climate, finds on return to the home of his youth that the mechanism of heat regulation does not readily adjust itself to cold damp winds and blizzards; the athlete who has learned to execute the greatest variety of "tricks" in the gymnasium and then settles down to a sedentary life finds after some years that he is almost as helpless as the man who gave no attention to such training. It is unnecessary to multiply examples. Efficiency in any direction is the result of continued use of organs and especially of continued training of the nervous system. As we fit ourselves to do some few things, and to do them well, we have not time to conserve by use the efficiency of all the nervous mechanisms we have acquired; we must to some extent sacrifice the more general actions for those which are more special and useful. But it must not be forgotten that this can be carried too far; that *a certain amount of general activity is a condition of healthy living* and that one of the problems of life to solve, and to solve aright, is how to distribute our activity between the two. To the consideration of these questions we shall return in our study of personal hygiene.

CHAPTER XVI

FOOD ACCESSORIES, DRUGS, ALCOHOL, AND TOBACCO

1. Food accessories and drugs. Through the alimentary and respiratory tracts there are received into the blood not only substances such as proteins, gelatin, fats, carbohydrates, salts, and water, which we have described as supplying the material for power and for growth and repair, but also other substances capable of modifying in one way or another the course of events within the body. The flavors which contribute to the enjoyment of foods play an important rôle in the secretion of the gastric juice, and yet the substances which cause these flavors are negligible as sources of power. Salt belongs under the same head, for we use in cooking more salt than is needed to make good the daily loss from the body, and we do this to develop an agreeable flavor in our food. Substances of this kind are spoken of as *food accessories*, and among them must be included coffee and tea, for their effect is not chiefly a matter of nutrition; certain constituents of tea and coffee absorbed into the blood affect the nervous system, and it is largely for this reason that we use them.

We may pass in this way from the necessary food accessories through those, like coffee and tea, which, while not essential, may still be regarded as part of the food of a large portion of mankind, to the great number of chemical compounds known as *drugs*, which also act by changing the course of events within the body; and it is difficult to draw any sharp line of distinction between those which occasionally serve as medicine or "stimulants" and those of which daily use is made as food accessories.

Animals as a rule take substances into their bodies only to satisfy hunger or thirst or appetite; man alone takes, in addition to his nutriment, food accessories and drugs for the sake of their special effect upon the nervous system or other organs. Many of the numerous food accessories which human ingenuity has discovered or devised are harmless enough in the form used, but others contain substances which are capable of poisoning the body. It is an important part of the study of personal hygiene to learn of what these substances consist, what is their action on the human organism, and wherein lie their special dangers.

2. The drug habit. It is a lamentable fact that large amounts of drugs are swallowed by men and women apart from any medical need which compels their use. In a subsequent chapter we shall show reasons for avoiding an undue dependence upon drugs as a remedy for various minor ills. Bad as this practice is, with its tendency to rely upon the uncertain action of a drug instead of taking proper hygienic care of the body, it is far worse to make habitual use of drugs for their special effects upon the healthy body, for the habit is one which is only too easily cultivated. There is no reason why a healthy human being, living a normal life amid healthful surroundings, should need to use drugs habitually, and a little consideration will show that the practice is dangerous.

3. Dangers of the drug habit. When we eat meat or vegetables, or when we breathe air, we take into the body materials needed for normal living. These things have always formed part of the food of the race and, unless wrongly taken, do good and not harm. When, on the other hand, we take a drug, such as chloroform, or cocaine, or opium, or alcohol, or coffee, or tea, we take something which is foreign to the body, in so far as it has not been a regular constituent of animal food in the past. It is not needed, as protein and salt and water are needed; there is no special preparation for its reception; and while it may do good, there is danger that it may do harm.

In the second place, the exact action of many drugs is only imperfectly understood. In an emergency the physician uses them *temporarily*, for some effect which he desires to produce, thus tiding over a difficulty. He uses the drug only a few times, at most, and is consequently not greatly concerned about unfavorable attendant effects; it accomplishes some needed purpose, and if it does any harm, the organism may be trusted to recover from it. It is very different, however, with the *habitual* use of any drug. The very fact that it gives some new direction to the events taking place within the body means that abnormal conditions of life are being maintained, and we have already learned that abnormal conditions of life are apt to be unhygienic.

Again, the use of drugs is only too apt to be substituted for the hygienic conduct of life. We may, for example, take drugs to accomplish something which the healthy body should accomplish for itself without outside help. When one drinks a cup of black coffee to facilitate mental work which his fatigued condition would not otherwise allow him to do, he is trying to get from a drug the power which he could and probably should secure by normal sleep. The coffee acts like a whip to a tired horse; the same work is done as might have been done had the horse been allowed a little rest, but the horse is not as well off when he does the work under the lash as when he does it in a properly rested condition. Similarly, persons suffering from sleeplessness often take drugs used to produce sleep (hypnotics), and, superficially at least, the sleep thus secured resembles normal sleep; but experience shows that few if any hypnotics can be used for any length of time without bad effects. Here again a drug is being depended upon to do what the normal body should do for itself. Pepsin tablets may be taken to aid digestion, and thereby an attack of indigestion may sometimes be prevented or relieved; but a healthy stomach should furnish its own pepsin, and the fact that it does not do so is a sure warning that something is wrong in the conduct of life. It is irrational to neglect the duty of attending to the cause of the ailment, and it is foolish to substitute temporary relief for permanent cure. Perhaps if the drug did *all* that the proper care of the body does, *and did no more*, no serious objection could be made to its use; but there is probably no drug of which this is true, and for this reason it is foolish and rash to try to substitute the use of drugs for the hygienic conduct of life.

Lastly, if the drugs do not accomplish in the long run what should be done by the hygienic conduct of life, their extensive use becomes all the more dangerous in view of the unquestioned fact that we are apt thereby to become their slaves. Every man is the slave, broadly speaking, of the habits he forms, and it is only a question as to whether he will be the willing slave of good habits or the abject slave of bad habits. The man who leads a hygienic life is the slave of muscular activity, of correct feeding, of proper clothing, of rest, etc.; that is to say, these things become necessary to his life; he cannot get along without them. If for these proper agents of health he persistently substitutes some drug, whether it be alcohol, or tobacco, or coffee, or tea, or chocolate, or opium, the habit of using the drug is substituted for that of maintaining normal conditions. But since drugs cannot *entirely* take the place of such conditions, the constitution goes from bad to worse, and increasing dependence must be placed upon the drug. It is a safe rule that whenever we are uncomfortable or unhappy without the use of a certain drug we should cease using it until, with the help of hygienic living, we can get along without it.

There are people who are slaves of coffee, of tea, of chocolate, of patent medicines, of candy, and of soda water just as truly as there are slaves of tobacco, or of alcohol, or of opium. It is worse to be the slave of alcohol than of coffee, because the evil consequences of alcohol are greater than those produced by the corresponding use of coffee; but it is by the same process in both cases that the man or woman becomes a slave to the drug, and that process is the formation of bad habits.

With these practical considerations about the use of drugs — by which term it will be seen that we mean not simply the medicines purchased from the apothecary but all those substances which are taken into the body in order to give some new or abnormal direction to the course of events in the organism — we may pass on to the discussion of those in common use.

4. Tea and coffee. Different as are these drinks in taste and appearance, their most important physiological effects are due essentially to the same substances; namely, *caffeine* (or theine) and *tannic acid* (or tannin). Caffeine is a very powerful stimulant, especially of the nervous system and also of the heart, although probably to a lesser degree; tannin, on the other hand, is a bitter, astringent substance, which may considerably hinder digestion and directly injure the mucous membrane of the stomach. Tea contains about twice as much tannin as an equal weight of coffee, but as coffee is frequently made much stronger than tea, the actual amount per cup may often be more nearly equal in the two drinks than these figures indicate. The amount of tannin dissolved in tea varies greatly with the method of preparation, and largely for this reason tea should not be boiled nor allowed to steep too long. The proper method of making tea is to pour over the dry leaves water which has been brought just to the boiling point and then to allow the infusion to stand, without further heating, for not more than a few minutes.

Both tea and coffee seem to have a slightly retarding influence upon gastric digestion. In healthy people this is of little consequence, but when the digestive powers are in any way impaired, the use of these beverages may be inadvisable. The more important effect, however, of both tea and coffee is in their stimulating action on the nervous system. No satisfactory explanation has yet been given of the fact that some people can use tea and not coffee, while with others the reverse is true. It is probably safe to say that when used in moderation, tea and coffee are usually harmless to those leading an otherwise hygienic life. They should be used sparingly by nervous people and by those in whom digestion is feeble and slow (Hutchinson). Even by the perfectly healthy they should not be used to excess, nor should the habit be acquired of using them as the whip to the tired horse. Drinking strong coffee in order to keep awake for evening study is objectionable, and the substitution of afternoon tea for a little rest or sleep is also unwise.

5. Cocoa is made from the seeds of trees of the genus Theobroma, and *chocolate* is prepared from cocoa. In the solid form both are highly nutritious, as shown by the following average results of analyses:

	Protein	Fat	Carbohydrate
Cocoa	21.6%	28.9%	37.7%
Chocolate	12.9%	48.7%	30.3%

When used as a beverage, however, the nutriment derived from them is small. In addition, cocoa and chocolate both contain *theobromine*, a substance closely related chemically to caffeine and possessing much the same stimulating properties. In general, the same hygienic considerations which apply to the use of tea and coffee should guide us also in the use of chocolate and cocoa.

6. Soda water and similar beverages. Of these little need be said. In general, they are harmless enough, especially to those enjoying perfect digestion. The large amount of sugar which they contain is apt to make matters worse in many cases of dyspepsia; by taking them frequently between meals the appetite for wholesome food is impaired, and excessive indulgence in them under any circumstances is needless and foolish.

7. Alcoholic beverages. In the case of an alcoholic drink we have to deal with something which, like tea and coffee and cocoa and "temperance drinks," is used as a beverage, and to that extent must be classed in the same group. Alcoholic drinks are, however, taken as stimulants and so resemble tea and coffee and cocoa, but they differ from all of these in their action upon the body. Moreover, their abuse gives rise not only to degraded moral and social conditions, but is also attended with bad hygienic effects. Everyone should be informed of their nature and of the dangers attending their use.

The common alcoholic beverages consist of (1) *malt* liquors, including beer and ale; (2) *wines*, such as hock, claret, Burgundy, sherry, and champagne; (3) *distilled* liquors, including brandy, whisky, rum, and gin; and (4) liqueurs and cordials. These groups are distinguished from one another largely by the method of preparation and by the amount of alcohol they contain. Malt liquors are fermented liquors which contain from three to eight per cent of alcohol; wines are also fermented liquors, but contain from seven to twenty per cent of alcohol; distilled liquors, on the other hand, are first fermented and then concentrated by distillation, and contain from thirty to sixty-five per cent of alcohol. In all these the most important constituent, so far as their physiological action upon the body is concerned, is the chemical compound known as *ethyl alcohol* (C_2H_6O or $C_2H_5 \cdot OH$).

8. Fermentation. The ethyl alcohol in each of these beverages is produced by the action of yeast on sugar, and this action is known as alcoholic fermentation. Yeast is a unicellular plant, and when a small amount of it is added to a solution of grape sugar or fruit sugar, it breaks up these substances, chiefly into alcohol and carbon dioxide gas. The latter passes off, while the alcohol remains behind in the solution. In addition to these chief products of fermentation there are always formed other products in small quantities, and to these, in part, the flavor of the fermented mixture is due. Different varieties of yeast produce different kinds of fermentation. Thus one variety (domesticated yeast) is used in making beer, and another (wild yeast) in making wine. The amount of alcohol produced differs with the yeast used, as do also the character and quantity of the secondary products. The growth of yeast, like that of all living ferments, is checked by the accumulation of the products of its own activity. Consequently when the alcohol produced reaches a certain percentage (usually less than ten per cent) the fermentation ceases. Alcoholic drinks which contain higher percentages of alcohol are prepared by special processes, which will be described later.

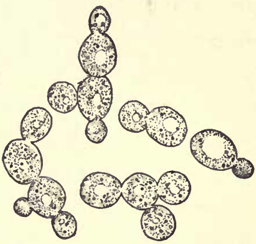


FIG. 117. Yeast cells

9. Malt liquors. Malt consists of sprouted grains (chiefly barley). The grains contain a large amount of starch which during the process of germination is converted into sugar by *diastase*, an enzyme produced by the living cells of the plant — the action of diastase being essentially similar to that of the ptyalin of the saliva. The germinating plant thus comes to contain considerable quantities of sugar, together with salts, proteins, and other substances. The watery extract of malt is known as *wort*, and it is this which, after being boiled with hops, is acted upon by the yeast. The liquid thus produced from wort by fermentation is known as ale, beer, stout, porter, etc., according to the conditions under which the fermentation takes place and the character of the malt and the yeast employed. German beers contain from three to four per cent of alcohol; ale contains from four to six per cent.

10. Wines. Wine is produced by the fermentation of the juice obtained by crushing grapes, and the yeast comes from the "bloom" on the skin of the grapes. The juice, or "must," thus extracted is allowed to undergo fermentation, and the fermented liquid is wine. Most wines, however, are subjected to subsequent treatment. Some are allowed to ripen in wooden casks, during which process there take place chemical changes which give to each wine its peculiar flavor. In other cases the wine is "fortified" by the direct addition of alcohol. Wines differ from one another according to the variety of the grape used in making the must, according to the variety of yeast used for fermentation, and according to other circumstances.

11. Distilled liquors and spirits. This group of alcoholic beverages contains the highest percentage of alcohol, and includes whisky, brandy, rum, and gin. In the making of all of these the essential procedure is the same; namely, first to produce fermentation in some sugary liquid and afterwards to *distill* from the products of this fermentation its alcohol and some other volatile constituents. Whisky is made by distilling fermented corn or rye; brandy may be spoken of as distilled wine; rum is distilled from fermented molasses, and gin from a fermented mixture of rye and malt — juniper berries and other substances being added to the distilled product. In general, distilled liquors contain from thirty to sixty per cent of alcohol.

With these differences of preparation, alcoholic beverages differ greatly among themselves, independently of the quantity of alcohol they contain, and some of their special effects are due to other constituents. The *chief danger* of most of them, however, lies in the action of the ethyl alcohol upon the system, and we shall confine our discussion to the effects of this substance. The problem is by no means a simple one, because these beverages are used in so many different ways by different people. Moreover, the results of their use differ according to the constitution of the person using them and according to his other habits of life. Sweeping assertions are too frequently made, in good faith, only to be found false by experience in special cases, and in this way harm is done where good was intended. For example, it is often asserted that alcohol used in any amount whatever is a poison to the healthy organism. If this be so, it is the only known drug of which this is true. Dr. John J. Abel, from whom we shall extensively quote, says on this subject: "All poisons are capable of being taken without *demonstrable* injury in a certain quantity, which is for each of them a special though sometimes very minute fraction of their toxic or lethal dose. There is no substance which is always and everywhere a poison." Alcohol is a drug and, like many drugs, may be and frequently is used in poisonous doses, but it must not be supposed that its real danger lies in the fact that it always exerts a poisonous effect on the body.

12. The physiological action of alcohol. As to the immediate action of alcohol on the body we may say that it belongs in the same general class of drugs as the ether and chloroform used for anesthesia; in other words, its general action is that of a *hypnotic* or *anesthetic.* To quote again from Dr. Abel:

> An exhilarating action is an inherent property of these substances in certain doses. Occasionally the physician meets with persons who have formed the habit of inhaling chloroform from the palm of the hand or from a lightly saturated handkerchief. The inhalation is usually carried on for a short time only, and its object is to induce a pleasant form of mental stimulation. Only occasionally is the inhalation of chloroform carried on until helpless intoxication occurs.

And again:

> That alcohol can produce as profound anesthesia as any of the substances named is also well known. In the days before anesthesia it was the custom of bone setters to ply their patients with alcohol in order to facilitate the reduction of difficult dislocations. . . . The anesthesia produced by alcohol is, however, not commendable, since it cannot safely be induced in a short time and is too prolonged. The quantity needed for surgical anesthesia would in many cases lead to a fatal result.

13. Is alcohol a stimulant? The view of the action of alcohol just stated is, of course, borne out by the condition of a thoroughly intoxicated person; but it is opposed to the very general idea that alcohol, except in large doses, is to be regarded as a stimulant. Whether we shall call it a "stimulant" or not depends upon how we use that term. Some of the exhilarating effects of alcoholic drinks might lead us to speak of it in this way. People who have drunk wine often become more talkative, so that the first effects of intoxication often resemble those of stimulation. There is, however, strong reason for thinking that this action is only superficially, and not fundamentally, a case of stimulation, as we shall now see.

In studying the physiology of the nervous system we found that processes of *inhibition* are as important in its operation as are those of *excitation*; and in mental operations the course of our thinking is constantly checked or inhibited by the knowledge of facts opposed to the conclusions towards which we are tending. *Probably it is this essential feature of all accurate and valuable mental work which is the first to be paralyzed by alcohol.* The man who takes alcohol becomes fluent not because he is stimulated but because of the removal of checks whose presence may make him talk less fluently, but which at the same time make him speak more accurately. He may become witty, and may say some brilliant things, but he will almost always do and say some very erratic things.

The following (by Dr. Abel) appears to be a sound statement of our present knowledge of this important subject:

Alcohol is not found by psychologists to increase the quantity or vigor of mental operations; in fact, it clearly tends to lessen the power of clear and consecutive reasoning. In many respects its action on the higher functions of the mind resembles that of fatigue of the brain, though with this action is associated a tendency to greater motor energy and ease.

In speaking of a certain type of individual James says: "It is the absence of scruples, of consequences, of considerations, the extraordinary simplification of each moment's outlook, that gives to the explosive individual such motor energy and ease." This description aptly applies to the individual who is under the influence of a "moderate" quantity of alcohol. It tends to turn the inhibitive type of mind into the "hair-trigger" type. We have said that the speech and the bearing of men, the play of their features, all bear witness to the action of alcohol on the brain; that it removes restraints, blunts too acute sensibilities, dispels sensations of fatigue, causes a certain type of ideas and mental images to follow each other with greater rapidity, and gives a "cerebral sense of richness."

Larger quantities, such as are for most individuals represented by one or two bottles of wine (ten per cent of alcohol), may, according to the resistance and type of individual in question, cause a lack of control of the emotions; noticeably affect the power of attention, of clear judgment and reason; and decidedly lower the acuteness of the several senses. In many individuals such quantities will develop so marked an anesthetic action that all phenomena of intoxication may be seen to follow each other in due sequence, finally to end in the sleep of drunkenness.

There has been much discussion as to whether alcohol is in any sense a stimulant for the brain. We have seen that pharmacologists of high repute deny that it has this action, holding that alcohol is a sedative or narcotic substance which belongs to the same class as paraldehyde and chloroform; that its stimulating action is but fictitious; and that even the earlier phenomena of its action are to be referred to a paralyzing action on cerebral (inhibitory) functions. This theory assumes an unequal action on cerebral functions in the order of time. Kraepelin, however, holds that this is a purely subjective analysis, and that in the early stages of its action alcohol truly stimulates the motor functions of the brain; that a state of mental exhilaration, of "motor excitability," may coexist with undiminished power of perception and judgment. His psychological experiments on the action of alcohol, taken all in all, do not, however, entirely prove his position.

Some cases of apparent stimulation are really due to the fact that alcohol, when taken in the form of wines and distilled liquors, sets up an irritation in the mucous membrane of the mouth, œsophagus, and stomach, which *reflexly* excites the heart to greater activity or for the time being *reflexly* stimulates the nervous system. Such stimulation is, however, transient and, as the alcohol is absorbed into the blood, gives way to depression and even stupor.

It is neither possible nor necessary to state here in full the reasons which have led to what seems to the authors the erroneous view that alcohol in small doses is a stimulant and only in larger doses a depressant and hypnotic. Enough has been said to show that there are at least two opinions about the matter: that even if alcohol is at times a stimulant, it is an uncertain stimulant, and that its excitation is liable to give way at any time to depressing effects. A critical examination of the literature on the subject has failed to demonstrate to us a direct stimulating action of alcohol on any of the functions, such as the beat of the heart, respiration, digestion, etc. At times, especially in sickness, alcohol may be useful; but the evidence tends to the conclusion that where it exerts any physiological action on the healthy body at all, that action is usually depressing. This is notably true as to the beat of the heart, as to respiration, and as to the ability to do muscular work.

We have dwelt at length upon this question in order to disabuse the student's mind of the idea that alcoholic drinks can be safely depended upon as an aid in the performance of work. Few causes are more effective in leading to the abuse of alcohol than the idea that when one finds difficulty in doing a thing it may be accomplished more easily by having recourse to beer or wine or whisky for their "stimulating" effect. In general, so far is this from being the truth that the person seeking such aid is really using a hypnotic and depressant. Obviously he would be acting more wisely to adopt other methods of accomplishing his end. Nor is this conclusion merely theoretical. Brain workers who wish to "keep a clear head" almost universally avoid alcoholic drinks, at least until work is over.

14. Alcohol in muscular work. That the general effect of alcoholic drinks is to depress rather than stimulate the powers of the body is furthermore indicated by the results of experiments on men doing heavy work, as, for example, soldiers on forced marches. In the Ashanti campaign the effect of alcohol as compared with beef tea was tested. To quote from Sir Lauder Brunton:

> It was found that when a ration of rum was served out, the soldier at first marched more briskly, but after about three miles had been traversed the effect of it seemed to be worn off, and then he lagged more than before. If a second ration were given, its effect was less marked, and wore off sooner than that of the first. A ration of beef tea, however, seemed to have as great a stimulating power as one of rum, and not to be followed by any secondary depression.

The results of these and other experiments lead us to the conclusion that alcohol cannot be depended upon to increase the capacity for hard muscular work and that in the great majority of cases it actually diminishes it.

15. The dilation of cutaneous arteries by alcohol. One of the most important effects of alcoholic drinks is the dilation of the arteries of the skin, thus sending more warm blood to the surface. It is a common experience among persons not accustomed to alcoholic drinks that even a small amount "makes the face hot" and flushed, and the red face of the toper is proverbial. The result of this dilating effect is that the temperature of the skin rises and the individual feels warmer. Congested states of internal organs may thus be relieved, and this is probably one reason why men leading an exclusively sedentary life often use alcoholic drinks apparently to some advantage. But even these would do infinitely better to secure the same result by proper muscular activity.

Even if a temporary advantage appears to be gained in some cases or at some times, this has often to be paid for by bad secondary effects, such as impaired capacity for good work some hours later; and in mental work of the highest kind, such as original writing or composition, the after effects of alcoholic drinks are sometimes prolonged and easily detected by the subject of the experiment.

16. Alcohol as a defense against exposure to cold. Because of this effect upon the cutaneous circulation alcoholic drinks are frequently used by men exposed to cold, with the mistaken idea that the conditions within the body are thereby improved. The student has, however, learned (p. 193) that a *feeling* or *sensation* of warmth does not necessarily indicate greater heat production within the body; and he also knows that bringing the blood to the skin when the body is exposed to cold serves to increase the loss of heat. As a matter of fact the internal temperature often falls when alcohol is taken under these conditions. The story is told of some woodsmen who were overtaken by a severe snowstorm and had to spend the night away from camp; they had with them a bottle of whisky, and, chilled to the bone, some imbibed freely, while others refused to drink. Those who drank soon felt comfortable and went to sleep in their improvised shelter; those who did not drink felt very uncomfortable throughout the night and could get no sleep, but in the morning they were alive and able to struggle back to camp, while their companions who had used alcoholic drinks were found frozen to death. They had purchased relief from their unpleasant sensations of cold at the cost of lowering their body temperature below the safety point. This, if true, was, of course, an extreme case; but it accords with the universal experience of arctic travelers and of lumbermen and hunters in northern woods, that the use of alcohol during exposure to cold, although contributing greatly to one's comfort for the time being, is generally followed by undesirable or dangerous after effects.

17. Alcohol as a food. There has been much discussion as to whether alcohol is or is not a food; that is, whether its oxidation within the body may supply energy. This question must now be answered in the affirmative, although whether it can do more than supply heat to maintain the body temperature, — that is, whether it can also supply the power for muscular work, as do fats and carbohydrates, — we cannot in the present state of our knowledge positively say. In many cases of sickness the oxidation of alcohol is probably a useful source of heat production, since it is absorbed quickly and without digestion, but the healthy man does not and should not use it in this way. The amounts which would be required to be of any considerable service as food are far beyond those in which it may be used with safety. In other words, in using alcohol for food one would be obtaining heat at the cost of direct injury to many organs and also at the cost of impaired working power. Moreover, men do not use alcohol as a food; they use it as a drug. So that while the action of alcohol as a food is of practical importance to the physician, who must deal with the abnormal conditions of disease, its action as a food is not a matter of practical importance to healthy people.

18. Pathological conditions due to the use of alcohol. When alcoholic beverages are taken in excessive amounts we have the sad and degrading spectacle of a "drunken spree." Whether or not the drinker at first appears bright or witty, sooner or later there is presented the pitiable picture of complete loss of nervous coördination and control. The man becomes silly, or maudlin, or pugnacious, as the case may be, but always irrational; he staggers, stumbles, or falls; and finally passes into a drunken stupor. In this event the victim of his own indulgence is said to be "dead" drunk, or "intoxicated," being as it were thoroughly *poisoned.* If such intoxication is frequently repeated, there is a complete breakdown of the nervous system; the victim of alcoholic indulgence becomes a raving maniac and, with disordered vision, thinks he sees all about him snakes or foul vermin (*delirium tremens*). The silly or foolish stage of this poisoning sometimes provokes smiles or laughter in thoughtless observers, but none can witness the more serious consequences of repeated intoxication by alcoholic drinks without disgust and horror.

Many steady drinkers, even though they have never been drunk in their lives, are apt ultimately to acquire various diseased conditions of the body, into which we cannot enter in detail. The heart may be injured, or the arteries become diseased; the repeated irritation of the stomach may produce chronic gastritis; or the connective tissue of the liver and kidneys may increase, thus crowding upon the living cells and ultimately throwing a large part of them entirely out of use. While it must not be supposed that drinking alcohol is the sole cause of these troubles, — for some or all of them may come from other causes, — the frequency of their occurrence in steady drinkers is suspiciously high, and this has led to the very strong conviction among medical men that alcohol plays a large rôle in producing them.

19. Summary of the action of alcohol as a drug. In small doses alcohol may be completely oxidized within the body without exerting any pharmacological action. In the forms and amounts usually employed in alcoholic beverages it exerts, *in general*, a hypnotic or anesthetic action; the result on the system as a whole depends on the amount taken, and varies from the paralysis of inhibitory processes to the depression of all nervous functions, ending in drunken stupor. Continued excess may produce exaggerated forms of temporary insanity, among which delirium tremens may be mentioned. There is, moreover, good reason for believing that steady drinking is very frequently an important agent in preparing the way for many other diseases, and is hence a serious menace to health.

20. The seat of the danger in alcoholic drink. The regular use of alcoholic beverages is dangerous for the same reason that the regular use of any drug is dangerous. We are too apt to rely upon the drug to do for us what we ought to accomplish only by the hygienic conduct of life; the drug never satisfactorily does the work, and we go from bad to worse, and become its slave. But there is certainly greater danger in hypnotic drugs, like alcohol, than in true stimulants, like coffee, and cocoa, and tea. We need to have ourselves well under control when we use any drug; the highest faculties of the mind must keep tight rein or we may lose control of ourselves. With hypnotic drugs — to which class belong not only alcohol but ether, chloroform, opium, chloral, etc. — there is special danger that these powers of control (inhibition) may be stealthily paralyzed before we know it. Of course thousands of people use alcohol in moderation and never become drunkards; but thousands also, with no intention of using it to excess, do unconsciously let the reins drop, and before they know it the drug gets the better of them. Experience shows that it is with the hypnotic drugs that this most frequently happens.

Again, if we make a habit of taking alcoholic drinks, we are specially exposed to temptation from our fellow men to go too far. For the most part, people take coffee and tea or do not take them, as they please; no one urges them to use these drinks when they are disinclined to do so. To a less degree the same thing is true of tobacco, although here the force of fashion and example is stronger. But with alcoholic beverages the custom of "treating" makes the exercise of self-restraint more difficult than it would otherwise be, for here we are dealing with a drug which is capable of *impairing self-control.* Some one "treats" a friend to a drink; the friend wishes to return the compliment and so they drink again; the person with deficient self-control—and what little he has now lessened—insists upon a third, and so on, perhaps to intoxication. This, of course, does not always happen; thousands are strong and escape the danger, but thousands are weak or do not know better, and many a week's wages has gone in this way, leaving behind poverty and misery and impaired capacity before the close of Saturday night.

21. Concluding remarks on the use of alcoholic beverages. In the foregoing pages we have stated the salient facts concerning the physiological action of alcohol and alcoholic drinks. It only remains to point out for the student the obvious conclusions to be drawn from them and from the long and, on the whole, very sad experience of the race with alcoholic drinks. The first is that except in sickness and under the advice of a physician, alcoholic drinks are wholly unnecessary and much more likely to prove harmful than beneficial. The second is that their frequent and especially their constant use is attended with the gravest danger to the user, no matter how strong or self-controlled he may be.

It is true that history and romance and poetry contain many attractive allusions to wine and other alcoholic drinks, and it may also be true that such drinks, by loosening tongues and breaking down social, political, or other barriers (removing inhibitions), may tend towards conviviality and good-fellowship; but it is no less true that the path of history is strewn with human wreckage directly due to alcohol; that many a promising career has been drowned in wine; and that indescribable misery follows in the trail of drunkenness. The only absolutely safe attitude toward alcoholic drinks is that of total abstinence from their use as beverages.

22. Opium, morphine, and the opium habit. The danger of the use of drugs as a regular habit of life is perhaps most painfully illustrated by what is known as the opium habit. Among the most valuable remedies at the physician's disposal is opium or its active principle, morphine, which possesses remarkable power to produce insensibility to pain. It sometimes happens, however, that by incautiously using this drug for this purpose men and women become addicted to the habit. They finally cannot do without the drug, and its constant use causes an appalling moral and physical degeneration; so far indeed does this often go that the victim will commit crime in order to obtain the drug. It should be clearly understood that it is unsafe for anyone to use opiates to relieve pain; indeed, these should *never* be used except when prescribed by a careful physician.

23. Chloral, cocaine, etc. Men and women may become slaves to the use of other drugs and in much the same way as they become slaves to alcohol and morphine. Among these drugs are chloral and cocaine. They belong in the same general group of hypnotics or anesthetics, and the habit acquired is perhaps no worse than the opium habit. It is certainly very little better. Let the student remember that the root of the evil here, as elsewhere, is the substitution of the use of the drug for normal habits of healthful living.

24. Tobacco. The physiological effects of tobacco are quite complicated, so complicated that it is difficult to make general statements with regard to them. The effects of chewing are quite different from those of smoking, and those of smoking, no doubt, vary according as the smoke is or is not drawn into the lungs (inhaled).

The leaf of tobacco contains a poison (*nicotine*) which exerts a powerful action on the heart and on nerve cells. It is not, however, proved that the bad effects of the use of tobacco are due entirely or even chiefly to this substance, but it unquestionably contributes to the physiological effects.

The smoke from tobacco also contains ammonia vapor which locally irritates the mucous membrane of the mouth, throat, nose, etc., and this irritating action at times acts as a stimulant to the whole system in much the same manner as do "smelling salts."

It has been recently suggested that, owing to the incomplete character of the combustion, tobacco smoke contains a small amount of the poisonous gas carbon monoxide (CO), and it is quite possible that some effects of smoking — especially where the smoke is drawn into the lungs (inhaled) — may be attributed to this gas; but the suggestion has not yet been submitted to the test of actual experiment.

Indeed, the physiological action of tobacco probably not only varies with the form in which the tobacco is used but is in any case the result of a combination of a number of factors partly physiological and partly psychical. We must here, however, confine our attention to the purely hygienic aspects of the matter.

Human experience shows that the unwise use of tobacco may unfavorably affect digestion, cause serious disorders of the heart, and impair the work of the nervous system. Those training for athletic events are usually forbidden the use of tobacco because it "takes the wind"; that is, makes impossible the most efficient training of the heart. Many employers have found that youths who smoke cigarettes are less reliable in their work; and this is only one instance of the effect upon the nervous system already referred to, the same result being observed in a diminished steadiness of the hand, often amounting to actual tremor.

These effects do not, of course, manifest themselves in their extreme form whenever tobacco is used, but it is probable that they are always present in some degree. Whether they are noticeable or not depends largely upon the ability of the constitution to resist them. Tobacco is thus often used without demonstrable bad effects when one is leading a hygienic life; but very often the habit, formed under these conditions, persists after the increasing intensity of occupation and the attendant cares and responsibilities of life result in neglect of muscular exercise and improperly directed nervous activity. As this neglect begins to tell on general health it is found that the unfavorable effects of tobacco become more pronounced.

Especially to be condemned is its use by those who have not attained their full growth. During youth nothing should be allowed to interfere with the best development of the heart and nervous system, and the use of tobacco endangers the proper development of both of these most important parts of the human mechanism. It can hardly be doubted that many a young man has failed to make the most out of life because the habit contracted in youth has struck in this way at the foundations upon which he had subsequently to build.

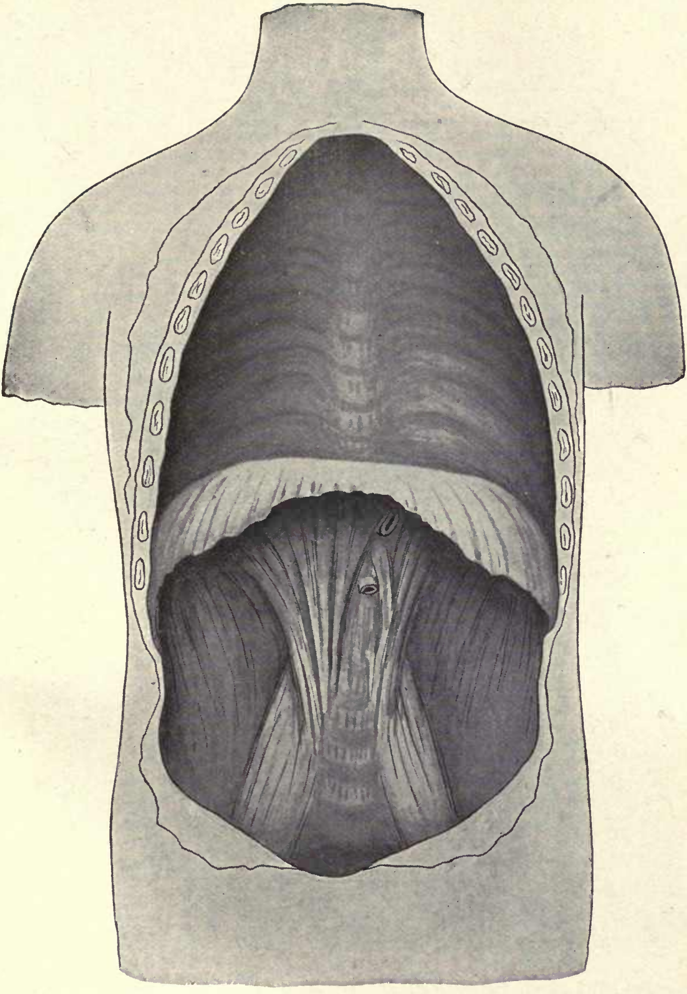


FIG. 154. The thoracic and abdominal cavities, after the removal of the organs shown in Fig. 2

The diaphragm has been drawn somewhat forward

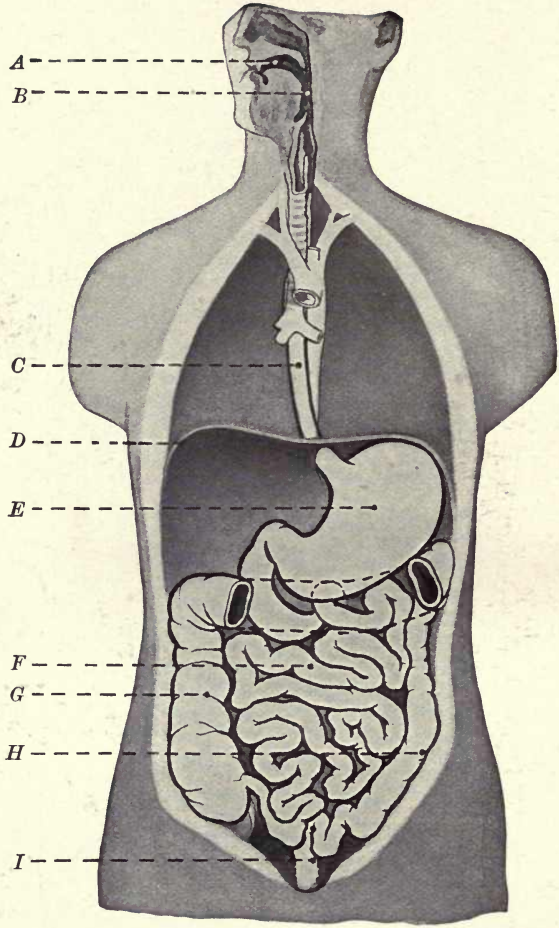


FIG. 155. General view of the digestive tract. After Spalteholz

A, mouth cavity; *B*, pharynx; *C*, œsophagus; *D*, diaphragm; *E*, stomach; *F*, small intestine; *G*, ascending colon; *H*, descending colon; *I*, rectum. The transverse colon has been cut away, its position being indicated by dotted lines

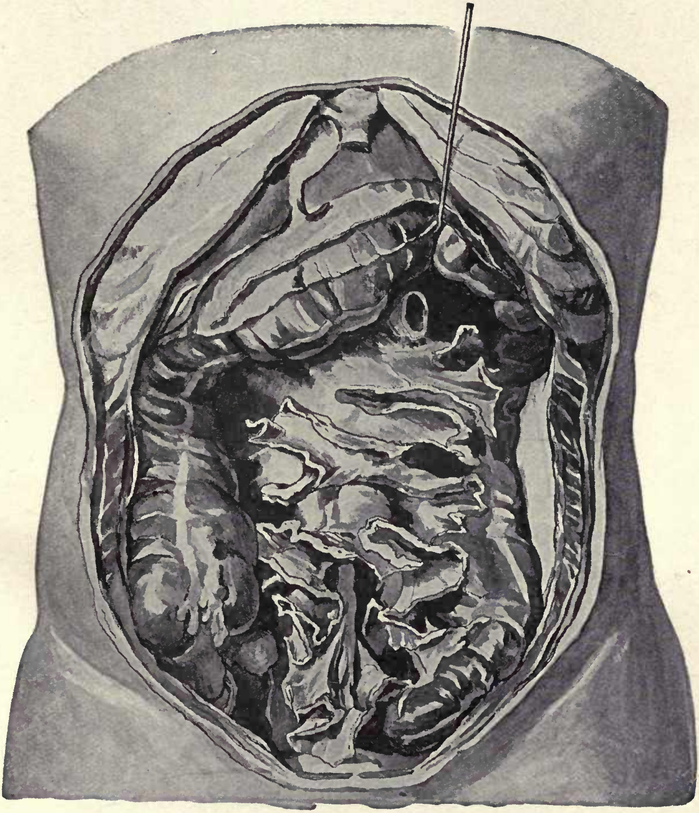


Fig. 156. The flouncelike folding of the mesentery, as seen after removing the small intestine. After Spalteholz

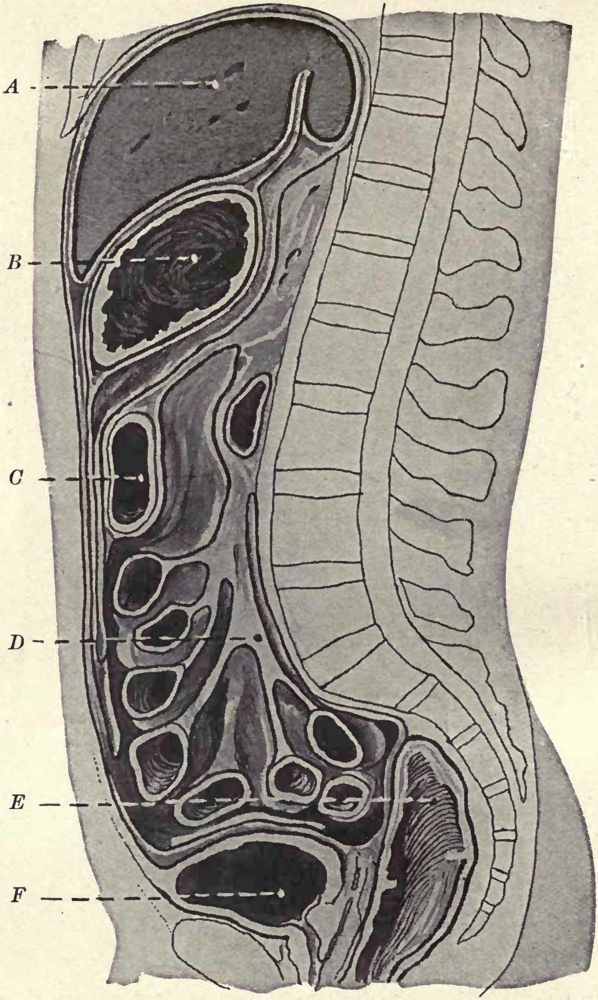


FIG. 157. Median dorso-ventral section of the trunk in the abdominal region, showing the suspension of the stomach and intestine by the mesentery. After Spalteholz

A, liver; *B*, stomach; *C*, transverse colon; *D*, mesentery; *E*, rectum; *F*, urinary bladder

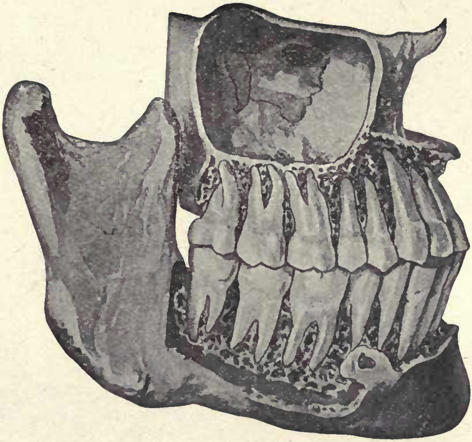


FIG. 158. The permanent teeth in the jaw-bones, viewed from the right. After Spalteholz

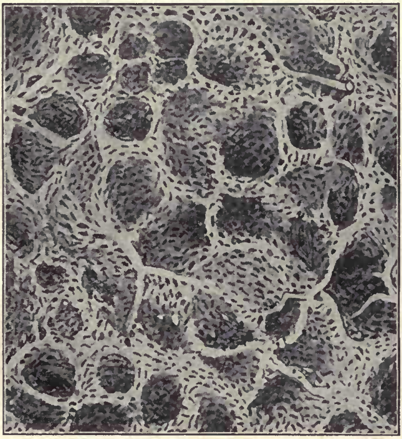


FIG. 159. The network of capillaries on the lining of the air cells of the lungs. After Kölliker

See page 169

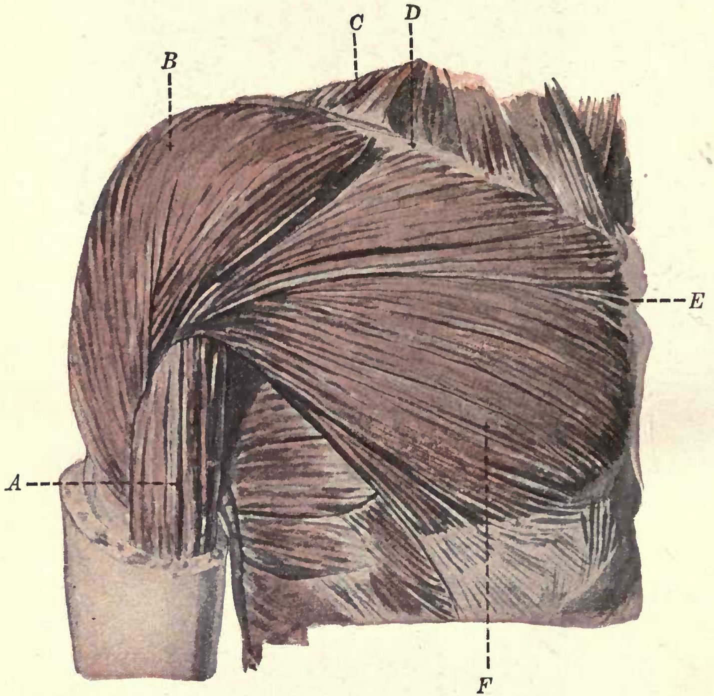


Fig. 160. First layer of muscles of the breast and shoulder region. After Spalteholz

A, biceps of the arm (p. 33); *B*, deltoid; *C*, portion of the trapezius (see Figs. 113 and 114); *D*, clavicle; *E*, sternum or breastbone; *F*, pectoralis major (see p. 316 and Fig. 114)

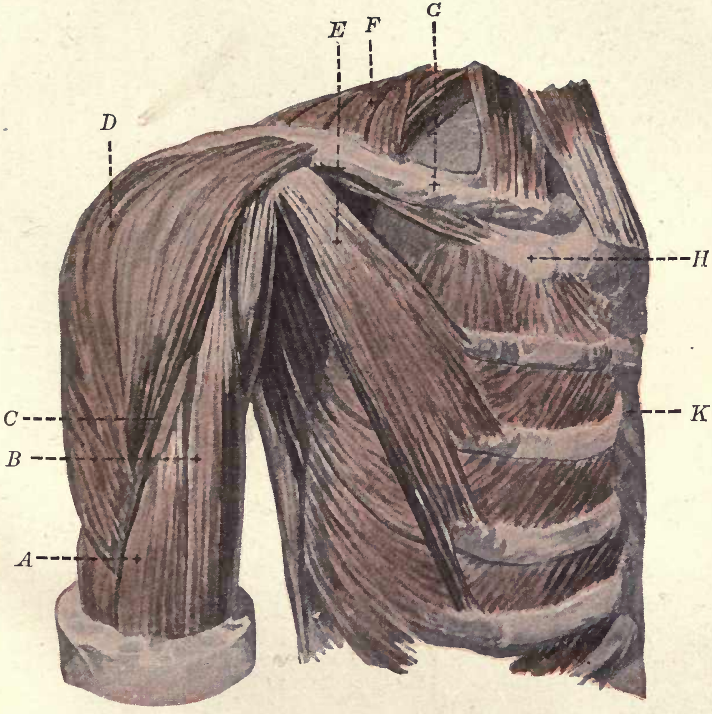


Fig. 161. Second layer of muscles of the breast, exposed by dissecting away the pectoralis major in Fig. 160. After Spalteholz

A, *B*, the two "heads" of the biceps; *C*, cut end of the pectoralis major; *D*, deltoid; *E*, pectoralis minor; *F*, trapezius; *G*, clavicle; *H*, first rib; *K*, sternum. Note the direct attachment of the intercostal muscles to the ribs (p. 8). Compare Fig. 160

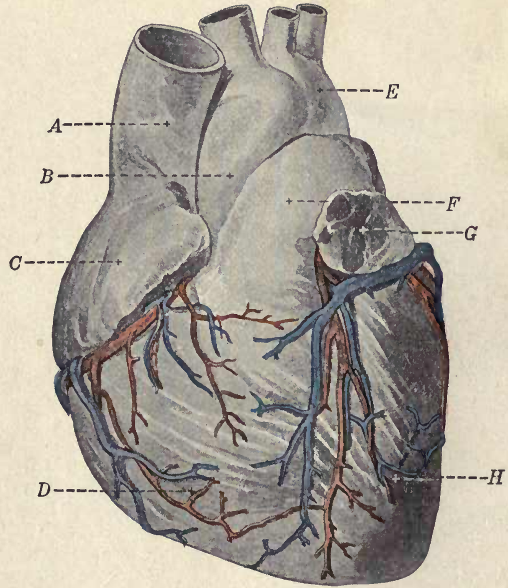


FIG. 162. Ventral aspect of the heart. After Spalteholz

A, superior vena cava; *B*, beginning of aorta; *C*, right auricle; *D*, right ventricle; *E*, arch of aorta; *F*, pulmonary artery; *G*, left auricle; *H*, left ventricle. Some of the chief arteries and veins of the heart are shown. The entrance of the pulmonary veins into the left auricle and that of the inferior vena cava into the right auricle are on the dorsal side of the heart and hence are not shown in the figure

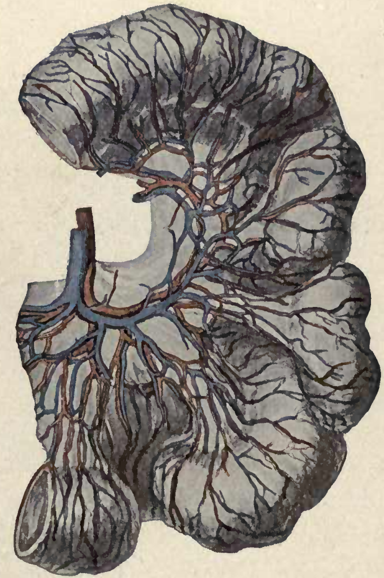


FIG. 163. A portion of the small intestine

Showing its attachment to the flouncelike mesentery, and the course of its arteries and veins in the mesentery (see p. 13). After Spalteholz

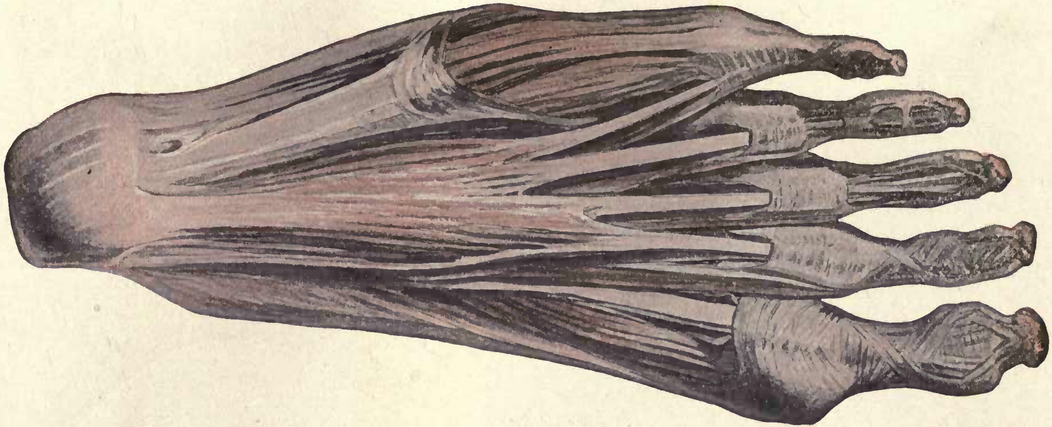
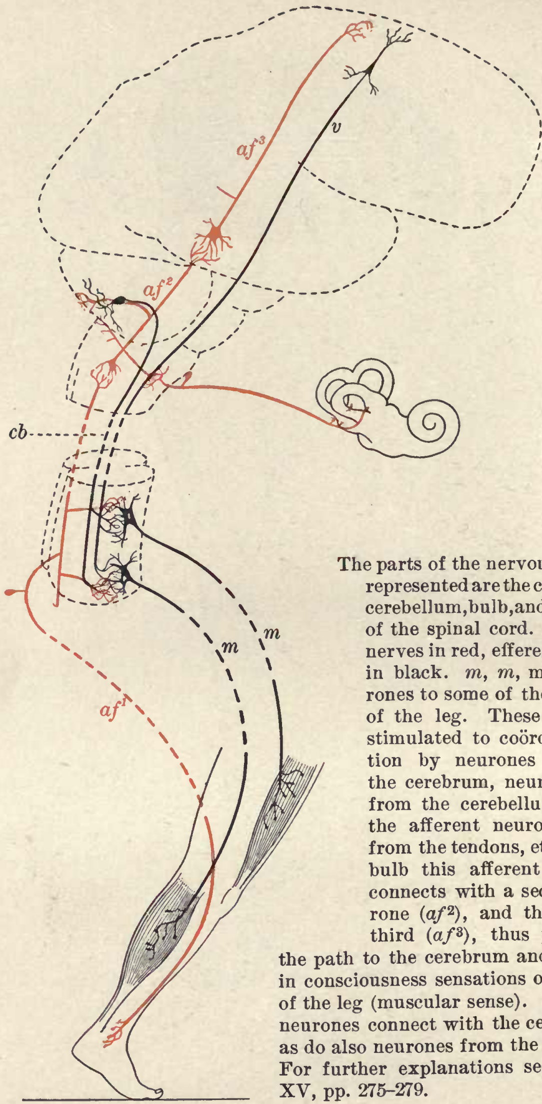


Fig. 164. Some of the muscles, tendons, and ligaments of the sole of the foot. After Spalteholz

Note the bowstring action of the muscles and tendons. For further description, see Chapter XXIV



The parts of the nervous system represented are the cerebrum, cerebellum, bulb, and segment of the spinal cord. Afferent nerves in red, efferent nerves in black. *m*, *m*, motor neurones to some of the muscles of the leg. These may be stimulated to coördinate action by neurones (*v*) from the cerebrum, neurones (*cb*) from the cerebellum, or by the afferent neurones (af^1) from the tendons, etc. In the bulb this afferent neurone connects with a second neurone (af^2), and this with a third (af^3), thus providing the path to the cerebrum and exciting in consciousness sensations of position of the leg (muscular sense). The same neurones connect with the cerebellum, as do also neurones from the inner ear. For further explanations see Chapter XV, pp. 275–279.

FIG. 165. Diagram of the nervous mechanism of walking

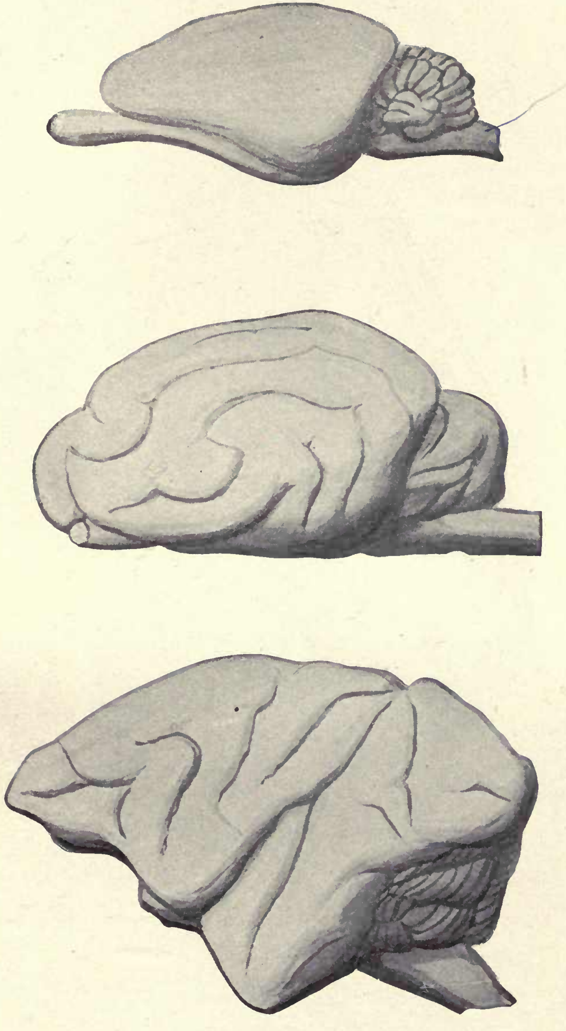


Fig. 166. Side view of the brains of rabbit, cat, and monkey

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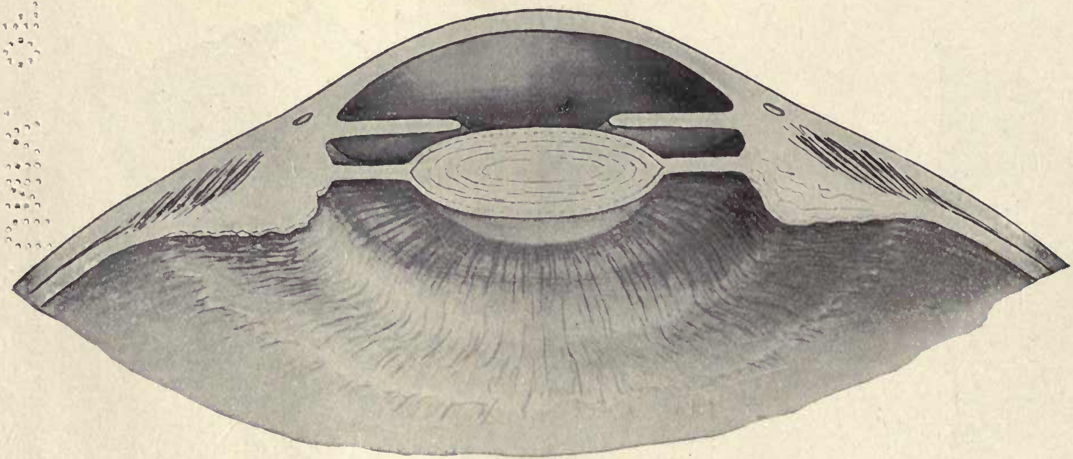

Fig. 167. Perspective view into the hemisphere of the eye

The names of the parts are given in Fig. 93, p. 244

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