Frederic S. Lee.

OUTLINES
OF
HUMAN PHYSIOLOGY

BY

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AUTHORIZED TRANSLATION FROM THE SECOND GERMAN EDITION

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WITH A PREFACE

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PREFACE TO THE AMERICAN EDITION

As the publishers wish me to write a preface to the translation of Schenck and Gürber's "Outlines of Human Physiology," I will briefly state my reason for having recommended the translation of this book. It seems to me that the present text-books of human physiology no longer adequately express our knowledge of the laws of life phenomena. A number of facts which throw new light upon the subject have been established by the extension of physiological research to Invertebrates, by the recently developed experimental or rather physiological morphology, and by the application of physical chemistry to physiological problems. It is uncertain how soon these new results will be embodied in the text-books of human physiology. The student will have to acquire his knowledge of these new subjects for the present from the study of monographs. In order to give him the time to do this the contents of the traditional text-book of human physiology should be made accessible to him in a more condensed form. To my knowledge no book answers this purpose better than Schenck and Gürber's manual.

I have had no connection with the translation. The credit as well as the responsibility belongs entirely to Mr. Zoethout.

JACQUES LOEB.

UNIVERSITY OF CHICAGO, November 2, 1900.

AUTHORS' PREFACE

Among the students of medicine there exists a need for an outline of human physiology which contains its most important facts in a concise form and gives the beginner a clear view of the entire field. It is true, such manuals exist—those of Oestreich, Breitenstein, Schmidt, Peter, etc.—but as these contain many errors, they can hardly be regarded as aids to the student, although in general use. For this reason it appeared advisable to publish this manual.

In regard to the arrangement of the material, we believe that we have not deviated to any great extent from the old and tried system. Our object has been to lay stress upon the undisputed facts, while we have not entered into the discussion of various unsettled questions. Yet in some instances we were compelled to mention the various hypotheses at present advanced.

The physiological methods are dealt with very briefly and often merely indicated by a few words, as it was not our intention to give elaborate descriptions of methods and apparatus. Moreover, by a shorter presentation of the methods the erroneous notion might be called forth that but little is necessary to understand it. Hence a mere allusion seems preferable, so that the student shall realize that this manual does not contain all that he needs to know, but that it gives only a survey of the general field of physiology and cannot take the place of lectures and larger text-books.

Most of the illustrations of this book are copies of figures found in well-known text-books and original papers. Many of the figures have been kindly loaned by the publishers of

Bernstein's Lehrbuch der Physiologie (Figs. 1, 14, 16, 17, 32–34, 37, 39–44, 46–48, and 51–53). We are indebted to F. C. W. Vogel (Leipzig) for the plates of Figs. 5–8 (from Hermann's Handbuch der Physiologie, Bd. V), to Edward Besolt (Leipzig) for the plates of Figs. 19, 22, 24, 45, 49, and 50 (from Rauber's Anatomie, etc.), and to Fischer (H. Kornfeld, Berlin) for Fig. 23 (from Lenhossek: Der feinere Bau des Nervensystems).

We are especially indebted to Professor Fick for advice received in the planning of this work.

Dr. F. Schenck.
Dr. A. Gürber.

Würzburg, October, 1897.

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INTRODUCTION

PHYSIOLOGY is the science of normal life. It may be divided into:

1. General Physiology, i.e. the science of the general properties of life or of the character of the living substance.
2. Special Physiology, i.e. the science of the vital phenomena of individual living beings (e.g. man, animals, plants), and of the single organs of the living beings.

This manual treats of the essentials of human physiology. As an introduction, a brief survey of general physiology is prefixed.

GENERAL PHYSIOLOGY

1. METABOLISM. IRRITABILITY

The **living body** contains no other elements and forces than those found in the inanimate world. There is no special "Vital Force." The properties of life are dependent upon the chemical and physical properties of the living substance. The composition of this substance is not known; in fact, it is a question whether it is chemically an individual substance or a mixture of different bodies.

The vital processes comprise chemical and physical processes—the changes of matter and energy [**metabolism**].

Metabolism consists of two processes: On the one hand, the living being continually splits up and, by the addition of oxygen, oxidizes the organic compounds which compose its body, thereby forming simple compounds (carbonic acid, water, ammonia and simple ammonia derivatives, e.g. urea); on the other hand, it again builds up its body substance from materials of the outer world. The former process is called **dissimilation**; the latter, **assimilation.**

The power of assimilation varies in different living beings. Plants containing chlorophyll are able, in the presence of sunlight, to assimilate very simple compounds (e.g. carbonic acid, water, nitrates), oxygen being set free. Certain Bacteria can assimilate free nitrogen. Animals, however, do not form their body substance from inorganic but from organic compounds which they obtain as foods from the plants. The animal body is able by reduction and synthesis to form higher organic compounds from the organic foodstuffs. The building of fats from carbohydrates is an example of a well-proven synthetical reduction taking place in the animal body.

The products of dissimilation of the animal world can be reassimilated by the plants, the water and the carbonic acid directly, but the ammonia derivatives only after they have been changed to nitrates by certain Bacteria found in the soil. Thus the circulation of the carbon, hydrogen, and nitrogen in the organic world is completed.

For the physiological combustion a continual supply of free oxygen is not necessary. Frogs can live for a long time in an atmosphere free of oxygen. In this case the organism obtains the necessary oxygen from the oxygen which has been stored up in its body in chemical combination. Many organisms, e.g. anaërobic Bacteria, can generally live in an atmosphere free of oxygen and still produce carbon dioxide, obtaining the oxygen from surrounding compounds which contain this element. Unlike the intensity of the fire in a furnace, the intensity of the physiological combustion cannot be increased by an increased supply of oxygen.

The theory of the **transformation of energy** is based upon the law of conservation of energy discovered by J. R. Mayer and H. Helmholtz. This law states that the total amount of energy in the universe always remains constant, that no energy is created or destroyed, and that energy can only change from one form to another. By means of dissimilation the stored-up chemical potential energy of the organic substance is changed to kinetic energy, mainly to heat and mechanical work, and, in smaller amounts, to electric force (e.g. in the electric fishes) and light (e.g. in fire-flies). The kinetic energy set free by dissimilation enables the living body to perform its functions.

By assimilation kinetic energy is transformed into chemical potential energy and is stored up in the organic substances. This energy is derived ultimately from the sunlight. Only in the presence of sunlight are plants containing chlorophyll able to assimilate. For assimilation not all the light-rays are suitable, only the red and yellow, not the green, blue, and violet. All energy which enables the living being to perform its functions is, therefore, sunlight changed to chemical potential energy.

The changes of matter and energy in the living being can be influenced by outside chemical and physical actions. Of special importance are the influences by which the dissimilation is increased. Such influences are called stimulating agents or **stimuli.** The increased dissimilation brought about by the stimulus is called **stimulation,** and the resulting activity is the external expression of the stimulation. The power of the living substance to respond to a stimulus is called **irritability.**

For example: A muscle stimulated by an electric current passes from the condition of rest into the condition of activity; by it the processes of combustion are greatly increased, the muscles shortened, and work performed.

The stimulus does not convey to the stimulated object the energy set free upon stimulation, but only calls forth the transformation of the already present chemical potential energy into kinetic energy, just as the fuse of the gun calls forth the explosion of the powder. Hence the effect of the stimulation is not proportional to the stimulus.

A stimulation produced at a given part of an irritable structure, e.g. a muscle-fibre, can spread itself throughout the entire structure by conduction.

The **stimuli** are classified as:

(1) *Chemical*,—those which, by means of chemical action upon the irritable substance, cause dissimilation. Electrical stimuli act as chemical stimuli because the current produces, by polarization at the places of entrance and exit, chemical changes which are able to stimulate.

(2) *Physical;* this includes mechanical (hitting, pulling); thermal (heating) and photical (light which, for example, stimulates the retina). The action of these physical stimuli can be reduced to a common principle, that of concussion, by which chemical changes producing stimulation are called forth.

Substances which can be decomposed by concussion are the explosive bodies; they are compounds in which the union of the atoms is unstable and which, by decomposition, form more stable compounds. The irritable substance of the living being is, perhaps, such an unstable compound.

Influences which decrease the amount of metabolism are called inhibitory agents and their effect is called **inhibition.** The condition of inhibition in which the vital phenomena entirely cease without the power of life being destroyed is called latent life or **biostition.** In biostition there are many living beings at the lowest temperatures which do not destroy life, also desiccated seeds of plants, spores of Bacteria, etc.

Strong stimulation can also cause inhibition, which is then called **fatigue** or exhaustion. This fatigue is due to the excessive consumption of irritable material and partly to the harmful effect of the dissimilation products (fatigue-substance) retained in the irritable structure. A fatigued structure at rest recovers by means of the reconstruction of the irritable substance and the removal of the fatigue-substance.

2. THE PHYSIOLOGICAL SIGNIFICANCE OF THE MORPHOLOGICAL ELEMENTS OF THE LIVING BEING

The characteristic chemical configuration of the living substance is connected with the structure or organization of the living being.

The structural elements, from which all living beings are built up, are called **cells.** The characteristic constituents of each cell are:

1. The **protoplasm,** a jelly-like mass, composed of a liquid ground-substance and solid constituents (protoplasmic framework, granules, chromatophores, and other inclosed objects);

2. One or more **nuclei** found in the protoplasm, generally spherical bodies composed of nuclear framework, nuclear sap, nuclear membrane, and nuclear corpuscles.

Protoplasm and nucleus are the bearers of life.

The cells which compose the living being are physiologically of very different value. From a physiological standpoint we can divide them into two groups:

1. Cells, each of which is an independent living being (physiological individuals), e.g. all unicellular organisms (protists); these are cells which possess all physiological activities necessary for the maintenance of life.

Simpler physiological individuals than cells are not known. Parts of cells (separate protoplasmic masses, single nuclei) are not capable of independent existence.

2. Cells not capable of existence by themselves, but only in physiological connection with other cells, for in them, as in the members of an organism, some physiological processes are strongly developed, while others are more or less undeveloped and taken up by cells of another kind. In this case many cells together build the physiological individual, and the processes necessary for the maintenance of life are distributed among the different cells of the individual. As in such cells the specially developed physiological processes

appear in an almost pure form, they are physiologically more simple, but for this reason also less independent, than unicellular individuals.

All organisms composed of many physiologically different cells develop from undifferentiated cells. The physiological differentiation is accompanied by a morphological differentiation, which is expressed in the various forms of the cells.

Although, in consequence of the division of labor, the various kinds of cells have different functions, yet those physiological processes which are connected with the characteristic constituents of all cells must be common to all kinds of cells. These physiological processes include in general the processes which belong to the nourishment and reproduction of the cells. These processes are governed by the nucleus. The nucleus of the reproductive cells is the bearer of the inheritable qualities of the organism.

The separation of the living substance into nucleus and protoplasm is the morphological expression of the physiological division of labor, the nucleus being predominantly concerned with the nourishment and reproduction, while the protoplasm chiefly reacts upon external influences.

3. GROWTH AND DEATH. ORIGIN AND DEVELOPMENT OF THE LIVING BEING

If in a living being assimilation and the addition of assimilated products predominate over dissimilation, **growth** of the organism results; if dissimilation predominates, the body decreases. In each organism the assimilation predominates at first, the body grows; later on the activity of assimilation decreases, the body begins to decrease, and this results in **physiological death** or in death brought on by senile decay.

A new living being originates only by the growing and the developing of a part separated from an already existing living body. This part grows and develops into a new living being either alone or after the union with a part of a second organism of the same kind. Life propagates itself from the mother- to the daughter-organism.

Nothing is known concerning the origin of the first living being on earth, from which all others are descendants.

The morphological phenomena of growth and development of a living being are the increase in cells and the development of form.

Cells multiply by fission.

In this process, the nucleus is divided into two nuclei; after this the protoplasm divides into two parts, each part surrounding one of the daughter-nuclei. The nuclear division is either direct by the fission of the nucleus or indirect. The indirect division takes place as follows: First the nuclear framework changes to a thick skein-like fibre; this fibre divides, by transverse section, into a number of segments, and each segment splits longitudinally into two halves, each of which goes to build up one of the daughter-nuclei. In this indirect nuclear division, the centrosomes have a definite influence. These structures lying in the protoplasm near the nucleus, in the form of two or more granules, divide, previous to the nuclear division, into two parts and these, by means of fibrilles which proceed from them, direct the course of the separating nuclear segments. (For details see text-book of Histology.)

The formation of a new organism results in one of two ways. Either some cells separated from the mother organism by cell division continue to exist by themselves independently and grow (asexual reproduction, reproduction by fission or budding); or two cells, derived from one or two sexually different living beings of the same species, unite to form one living being (sexual reproduction, union of egg- and sperm-cell).

The union of egg-cell and sperm-cell is the fertilization. In this the nuclei of the cells unite into one nucleus. By means of cell division, accompanied by cell differentiation, the new organism grows from the fertilized egg.

In many species of living beings (e.g. vascular cryptogams, hydromedusa) there is an alternation of generation in which one generation propagates itself asexually, and the other sexually.

The morphological development of the individual organism (**ontogeny**) results in the development of the daughter-organism, derived from a single cell, or from the union of egg-cell and sperm-cell, into a form similar or nearly similar to that of the mother-organism. The mother-organism transmits by **heredity** its characteristics to the daughter-organism.

The species of organisms existing at present have not always existed since the beginning of life, but have, in the course of time, been developed from simpler forms of life (development of species, **phylogeny**).

The forms which the growing organism assumes during ontogeny are similar to the forms which the adults possessed successively during the phylogeny. The ontogeny is a short recapitulation of the phylogeny (biogenetic law of Haeckel).

The cause of morphological development lies in the variability of the structure and functions of the living being, i.e. in the quantitative and qualitative variability in the transformation of energy and matter. The cause of this variability is not known.

The principle according to which Darwin's theory of selection explains the origin of species on the ground of variability is the "natural selection in the struggle for existence." The individuals of a generation of a certain species differ slightly because of their variability in structure and functions. Now, the struggle for existence which the individual carries on with hostile beings of the same or other species is endured best by those individuals which have the most advantageous characteristics. These individuals are therefore sooner selected for further existence and for reproducing offspring which inherit their characteristics. Such a selection, carried on through many generations, at last produces organisms which possess that characteristic developed to such an extent that they really differ from their ancestral organisms.

The continuous selection of advantageous variations leads to the development of beings highly fitted for their environment. In this manner originates the **adaptation** which we see in so many organs and organisms.

While the Darwinian theory explains the origin of species on the basis of the law of variability, it sheds no light on the cause of this variability; in other words, it does not explain the very condition necessary for the origin of species and therefore cannot be regarded as a complete explanation of phylogeny.

The principle of the Darwinian theory is, no doubt, applicable to the origin of many species. Whether it is by itself a sufficient explanation of phylogeny, or whether, besides it, external or internal causes are active, remains a question.

According to another theory (Lamarckian), any influence acting continually upon the descendants of an organism so as to produce the same changes will result in a change in the structure and functions of the organism, and this change is inherited. In this manner a new species originates.

Some authors assume that there is present in the living substance a fixed tendency to develop and perfect itself.

4. CORPOREAL LIFE AND SOUL LIFE

The problem of Physiology is the investigation of the objectively demonstrable processes of life. Besides these there are processes which can be perceived subjectively only. These are the phenomena of soul life, the conditions and processes of consciousness. The investigation of soul life is the province of Psychology.

Psychical processes are always accompanied by and dependent upon physiological processes in the central nervous system. The study of the character of the physiological processes which are associated with the psychical is, of course, a problem of Physiology. Hence, in the study of the central nervous system and sense-organs, the physiologist cannot ignore the facts of psychology, even though it is not his aim to explain the psychical phenomena.

Corresponding to the chief phenomena of life we may divide human physiology into the following parts:

1. Metabolism.
2. The transformation and setting free of energy.
3. Reproduction and development.

PART I

METABOLISM

THE combustible constituents of our body continually undergo chemical changes, in that they are burned by the inhaled oxygen.

The products of combustion are removed from the tissues, in which the combustion takes place, by the circulating blood and lymph; one of these products, the carbonic acid gas, is excreted from the body by the lungs; the other products, by glands.

That the body may continue to exist, new material for combustion must be supplied to it from without. This is effected by the partaking of nourishment which is made absorbable by digestion, and, after absorption, supplied to the tissues by the blood and then assimilated.

Metabolism, therefore, includes the following parts of physiology:

1. The chemical constituents of the body and their physiological importance.
2. Blood, the gases of the blood and respiration, circulation of the blood, respiratory movements, lymph.
3. Secretions.
4. Nutrition, alimentary principles, food, digestion, absorption and assimilation of the digested food.
5. Survey of metabolism as a whole.

CHAPTER I

CHEMICAL COMPOSITION OF THE HUMAN BODY

The fifteen elements of which the body is composed are present in about the following proportions:

Carbon, 18.5%   Oxygen, 65.0%
Hydrogen, 11.0%   Nitrogen, 2.5%

Sulphur, Phosphorus, Chlorine, Iodine, Fluorine, Silicon, Potassium, Sodium, Calcium, Magnesium, Iron,—together 3%.

The adult human body contains about 3 g iron. Other elements, traces of which are sometimes found, must be regarded as accidental constituents.

The body is, therefore, mainly composed of non-metals (metalloids).

Oxygen, nitrogen, and, in small quantities, hydrogen are the only free elements; only the free oxygen is of physiological importance.

The greater part of these and all other elements are found in both inorganic and organic compounds, in which they take the following parts, in detail:

1. **Carbon** forms the basis of all the organic compounds of our body. It unites with hydrogen and oxygen to form fats and carbohydrates; with hydrogen, oxygen, nitrogen, and sulphur, to form proteid bodies. It is, therefore, a constituent of the metabolic products of these substances and this chiefly in the form of carbonic acid, which is found throughout the body, partly in the free state, partly in the carbonates or bicarbonates of the alkalies and calcium.

2. **Hydrogen** is mostly ($\frac{3}{4}$) united with oxygen, forming water. With chlorine, it forms hydrochloric acid; with sulphur, sulphuretted hydrogen, found in the intestinal gases; with nitrogen, ammonia and its salts. Above all, it is one of the chief constituents of the organic compounds.

3. **Nitrogen** appears in the inorganic compounds only as ammonia, being united with hydrogen. It is found, however, in many organic compounds, of which the proteids with their derivatives and metabolic products are the most important.

4. Nine-tenths of the **oxygen** appears in the form of water; in small proportions it is present in carbonic, sulphuric, and phosphoric acids and their salts. Besides this, it is present in all organic compounds of the body (except in a few hydrocarbons in the intestine).

5. A small part of the **sulphur** is present in the sulphates; another, still smaller portion, in the sulphuretted hydrogen and iron sulphide (intestine); by far the largest part is found in the proteids, where it appears in two forms, as reduced (easily split off by boiling with alkali) and as oxidized (strongly united with the proteid molecule). It seems to be present in both forms in the metabolic products of the proteids.

6. **Phosphorus** seems to be present in inorganic and organic compounds only in the form of phosphoric acid which forms salts with alkalies and calcium, the calcium salt forming a chief constituent of the skeleton. Organic compounds containing phosphorus are lecithin, jecorin, protagon, nuclein.

7. **Iron,** deposited as inorganic, i.e. in a form demonstrable by the ordinary reactions, in the liver and spleen (probably as oxide), is found also in the contents of the intestine (as iron sulphide). Of special physiological interest are the organic iron compounds, the most important of which is hæmoglobin, the red coloring matter of blood. Many nucleo-albumins also contain a little iron. The organic compounds of iron which do not give the general iron reactions are called metal-organic compounds.

The elements thus far described are the most important as they are the *organogenic* elements, so termed because they form the organic substances of the body.

The other four elements which are united with organic substances, especially proteid substances, do not appear in metal-organic compounds, hence it is concluded that these elements are present in the organism only in the form of salts or inorganic compounds.

8 and 9. **Potassium** and **sodium,** in about equal proportions, uniting chiefly with carbonic, hydrochloric, and phosphoric acids, form acid and neutral salts. Potassium salts predominate in the tissue-cells, sodium salts in the tissue-fluids. The alkali-metals also form salt-like bodies with the proteids.

10 and 11. **Calcium** and **magnesium,** as the salts of carbonic and phosphoric acids, form the chief constituents of the bones. Calcium, either alone or with phosphoric acid, is also united with proteids.

12. **Chlorine** is present as free hydrochloric acid (in gastric juice); or united with an alkali, especially sodium, predominates in the tissue fluids. In gastric digestion, hydrochloric acid forms acid hydrochlorates with the products of proteid digestion.

13. **Iodine** is found in thyroiodine, a substance present in the thyroid gland of adult man.

14. **Fluorine,** united with calcium, is present in the enamel of the teeth.

15. **Silicon** is found in the hair; in which form it is present is not known.

The chemical compounds found in the body may, from a physiological standpoint, be divided into the following groups:

1. Inorganic compounds (water and salts), i.e. saturated compounds which cannot be transformed into more saturated compounds by chemical processes in the body and, hence, cannot furnish the body with energy for its functions. Their importance for life is due to their physical properties; they also take part in chemical actions, but no utilizable energy is thereby gained.

2. Organic compounds which serve as sources of energy for the organism (proteids, fats, carbohydrates); the stored-up chemical energy is set free by their physiological combustion.

3. Organic compounds which, as end-products of metabolism, are formed by the physiological combustion (nitrogenous end-products of metabolism, such as urea and others) and are destined to be excreted from the body.

1. THE INORGANIC COMPOUNDS OF THE BODY

1. **Water** is the most abundant constituent of our body, amounting to about 65% of the body weight of the adult. In new-born children the proportion of water is above 70%. The following table indicates the amount of water in the different tissues and organs:

Adipose tissue	15%	Pancreas	78%
Bones	50%	Blood	79%
Liver	70%	Lungs	79%
Skin	70%	Heart	79%
Spleen	77%	Kidneys	83%
Muscles	77%	Vitreous humor	98.7%
Brain and spinal cord	78%	Cerebro-spinal fluid	99%
Intestine	78%		

The physiological importance of water is as follows:

(*a*) It serves as a solvent and as such it renders possible physical and chemical processes such as diffusion, mechanical movement, and the chemical action of dissolved substances.

(*b*) As a means of imbibition, which determines the semi-solid consistency of the tissues.

(*c*) By evaporation from the lungs and body surface, it takes heat from the body and, hence serves as a temperature regulator.

(*d*) It takes part in chemical processes, e.g. in the hydrolytic splitting up.

2. **Bases** are not found in a free state but, united with **acids,** are present in the form of salts. As more than sufficient acids are present for the union with bases, acid salts are formed. Under certain conditions the existence of a free acid must be granted, namely, carbonic acid. **Hydrochloric acid** is found in a free state in the gastric juice; it is set free from sodium chloride by the gland-cell of the mucosa.

3. **Salts,** formed by the union of acids and bases, in which the hydrogen of the acid is replaced by the metal of the base, are present in the body to a large extent. When the tissue is burned the salts remain behind as **ash.** The ash, however, is not identical with the original salts of the body, as, by the incineration of the body, substances appear in the ash which were not present in that form in the organism. Originally they were present in organic compounds, e.g. iron as a constituent of hæmoglobin; part of the sulphuric and phosphoric acids were derived from the proteid, lecithin, and nucleins. On the other hand, certain salts originally present, as acid carbonates or phosphates, are converted into neutral salts by combustion. Very often the salts can be investigated only after the incineration of the tissue, therefore the ash and its constituents must be taken into consideration in studying the composition of the body.

The amount of the ash of the body is about 5% of the body weight, of which the skeleton furnishes over 80% and the muscles 10% The amount of ash in each tissue varies much with age and nourishment. The ash percentage of tissues is as follows:

Skeleton	22.0%	Heart	1.1%
Muscle	1.5%	Pancreas	1.0%
Liver	1.3%	Brain and spinal cord	1.0%
Spleen	1.2%	Blood	0.9%
Lungs	1.1%	Kidneys	0.8%
Intestine	1.1%	Skin	0.7%

The ash contains (with the exception of iron oxide) only neutral salts, derived from the bases potassium, sodium, calcium, magesium, and from carbonic, sulphuric, phosphoric, and hydrochloric acids. More than 80% are phosphates (chiefly calcium phosphate); the next largest in quantity are the chlorides (sodium chloride); then follow the carbonates and, last of all, the sulphates.

The salts of potassium and sodium, found in ash, are soluble in water, while the carbonate and phosphate of calcium and magnesium, iron oxide and iron phosphate are insoluble in water. In the body fluid the carbonate and phosphate of calcium and magnesium are acid and therefore soluble in water. The carbonates of the alkalies are also present in the body as acid salts (sodium bicarbonate).

When two or more salts of different bases or acids are dissolved in water, they exchange their components reciprocally, in such a manner that each base is united with each acid. In the body fluid there are four bases and four acids; according to this theory, sixteen salts ought to be formed. Moreover, the dibasic sulphuric acid and carbonic acid form two salts with each base, while the tribasic phosphoric acid forms three salts (the primary, secondary, and tertiary salts). According to the theory, therefore, many more salts must be formed. The quantity of each salt formed depends, however, upon the chemical affinity and upon the absolute quantity of the components entering into the reaction (law of mass action). Hence, many of the salts formed according to the theory may be present only in traces, and the number of salts to be considered is much reduced. In reviewing the salts of our body, an uncertainty always remains, so that the existence of many salts is not absolutely proved.

The most important salts of the body are:

1. **Sodium chloride** (common table-salt). This is chiefly found in the fluids of the tissues (0.6%); to a lesser extent, in the cells. It serves as a solvent for certain proteids (globulin) and supplies the osmotic pressure of the body fluid which keeps in equilibrium the osmotic pressure of the cells. This prevents the entering of water into the cells. In pure water, all tissue cells die, swelling rapidly. For this reason, in the investigations of living tissue, the so-called physiological salt solution (0.6% $NaCl$) is used. From the sodium chloride, the gastric mucosa forms the hydrochloric acid of the gastric juice.

2. **Potassium chloride** is the most important chlorine compound in the cells and serves to maintain the osmotic equilibrium. In the body fluids it is found in but small quantities and is not of any special physiological significance.

3. **Sodium carbonate** is chiefly found in the tissue fluids (0.2–0.3%). It imparts to these fluids their alkaline reaction and basic nature.

4. **Bicarbonate of sodium** is also found in the tissue fluids; it is the carrier of the carbonic acid formed by combustion in the body. (See Chapter III.)

5. **Potassium phosphate** (probably the secondary) is an important constituent of all cells. It is the most abundant salt in the cells. It is doubtful whether the salt is merely dissolved in the fluids of the cells or is united with their organic constituents.

6. **Neutral calcium carbonate** forms a part of the salts of bones, builds the otoliths of the ear, and perhaps also the crystals of the spermatic fluid.

7. **Acid calcium carbonate** is dissolved in the tissue fluids. It readily yields carbonic acid and is therefore, like bicarbonate of sodium, of importance as a carrier of carbon dioxide in the exchange of gases in respiration.

8. **Neutral calcium phosphate** is the chief mineral constituent of the skeleton, of which it forms one-fifth by weight.

9. **Acid calcium phosphate** is dissolved in the tissue

fluids. In the coagulation of blood it is supposed to aid in the formation of fibrin-ferment.

10. **Magnesium carbonate** and **magnesium phosphate** are present in the bones and often accompany the calcium salts, but in smaller quantities. Only in the muscles and in the thymus does the magnesium phosphate exceed the corresponding calcium salt.

11. In smaller quantities and without any known physiological importance are the following: *Potassium carbonate*, the *secondary sodium phosphate*, *sodium sulphate*, *potassium sulphate*, *magnesium sulphate*, *calcium fluoride* (in bones and enamel of teeth).

2. THE ORGANIC ENERGY-YIELDING COMPOUNDS OF THE BODY

A physiological principle according to which the following substances may be grouped is not yet known, as our knowledge of the rôle of each one in metabolism is still too limited. We may classify them from a chemical standpoint as follows:

1. Carbohydrates; 2. Fats; 3. Proteids.

1. The **carbohydrates** derive their name from the fact that, besides carbon, they contain hydrogen and oxygen in the same proportion as water. This characteristic has no reference to the chemical constitution of the substances.

The carbohydrates are aldehydes or ketones of hexatomic alcohols or anhydrid unions of two or more molecules of such aldehydes and ketones. Their number of carbon atoms is six or a multiple of six.

Heating changes all carbohydrates to caramel having a characteristic odor; they are all stained red by thymol and concentrated sulphuric acid.

They are classified as:

Monosaccharides. . . . . $C_6H_{12}O_6$;
Disaccharides. . . . . $C_{12}H_{22}O_{11}$;
Polysaccharides. . . . . $C_6H_{10}O_5$.

The monosaccharides and disaccharides are also called sugars; they have a more or less sweet taste, the disaccharides being sweeter than the monosaccharides. Sugars are soluble in water and alcohol, but insoluble in ether; they crystallize and dialyze. The polysaccharides are insoluble in water or form only colloidal solutions; they neither crystallize nor dialyze.

The **monosaccharides** (hexoses, glucoses) have the following constitution:

Aldehyde sugar (aldoses):

$$CH_2OH.CHOH.CHOH.CHOH.CHOH.\mathbf{COH}.$$

Ketone sugar (ketoses):

$$CH_2OH.CHOH.CHOH.CHOH.\mathbf{CO}.CH_2OH.$$

Characteristics of monosaccharides:

1. They are optically active, i.e. their solutions rotate the plane of the polarized light; most of them turn it to the right; only fructose turns it to the left (hence called levulose). The optical activity of the sugar is due to the presence of asymmetrical carbon atoms, i.e. carbon atoms whose four valences are united to four different radicles or atoms.

2. The aldehyde sugars, like all aldehydes, are easily oxidized, forming first monobasic and then dibasic acids. The ketoses are also oxidized, whereby they are, at the same time, split up into bodies containing less carbon. Upon this fact, that the sugars are oxidizable, depends the detection of sugar by the so-called reduction tests. Of these the following are the most important:

(*a*) *Trommer's test:* Sugar solution mixed with potassium hydrate and cupric sulphate, on boiling, gives a red precipitate, the cupric oxide having been reduced to the insoluble cuprous oxide.

(*b*) *Böttger's test:* Basic bismuth nitrate, by heating with sugar in an alkaline solution, is reduced to metallic bismuth (black precipitate).

(*c*) *Mulder's test:* Weak alkaline indigo solution, heated with sugar, loses its color through reduction.

3. *Moore's test:* Boiled with alkali, the sugar is oxidized and assumes a brown color.

4. In an acetic acid solution, monosaccharides, like aldehydes and ketones, unite with phenylhydrazine, forming hydrazones, water being set free. This, by the further taking up of a molecule of phenylhydrazine and the separation of the water and the setting free of hydrogen, forms phenylosazone. These compounds have characteristic crystals and melting-points which may aid in the detection of sugar.

5. Compounds of monosaccharides:

(*a*) Compounds of monosaccharides with bases are called saccharates. Lead saccharates are insoluble in ammonia and are therefore used for the precipitation of sugar.

(*b*) Compounds of monosaccharides with alcohols, phenols, aldehydes, and organic acids are called glucosides. By boiling with acids or by the action of many ferments, they are easily decomposed, under the assumption of water, into their components.

6. The yeast-cell splits up nearly all the monosaccharides into alcohol and carbonic acid (alcoholic fermentation); the bacterium lactis splits up most of them into lactic acid (lactic-acid fermentation).

Among the monosaccharides are grape-sugar, fructose, galactose, mannose. Grape-sugar is found in the animal body; the others are of importance as foods.

Grape-sugar (glucose in a more restricted sense, or dextrose) is the aldehyde of sorbit, a hexatomic alcohol found in the service-berry.

Grape-sugar is dextrorotatory (hence called dextrose), reduces and forms, with phenylhydrazone, phenylglucosazone, which crystallizes in branches having the melting-point at 204° C. It is capable of alcoholic fermentation. Its oxidation forms first gluconic acid (monobasic) and then saccharic acid (dibasic).

Grape-sugar is found in sweet fruits, in honey and, in small quantities, in the blood and lymph. It is the form in which most of the carbohydrates in the body are carried by the blood from one place to another (from intestine to the liver, thence to the tissues, where the physiological combustion takes place). Pathologically it appears, often very abundantly, in the urine (diabetes mellitus).

Glucosamin, $C_6H_{11}O_5NH_2$, is a nitrogenous derivative of grape-sugar which is transformed into grape-sugar by the action of nitric acid. It is obtained by the decomposition of chondroitin (a constituent of cartilage) or of chitin (a constituent of integuments of arthropods). This transformation is of importance in showing how carbohydrates can be derived from proteids.

Inosit, $C_6H_{12}O_6$, a sweet-tasting substance, does not belong to the sugars, as its carbons form a closed circular chain, six -CHOH-groups forming a ring, and is therefore hexahydroxy-benzene. Inosit is soluble in water, insoluble in alcohol and ether, optically inactive, does not reduce nor ferment with yeast, but undergoes lactic-acid fermentation. It crystallizes in prisms, grouped in rosettes. Successively treated with nitric acid, ammonia, and calcium chloride, it leaves, on drying, a rose-red spot. Inosit is found in muscles; its physiological importance is unknown.

Disaccharides are anhydrid compounds of two monosaccharide molecules of the same or different kinds:

$$2(C_6H_{12}O_6)_2-H_2O = C_{12}H_{22}O_{11}.$$

In this group belong:

Cane-sugar = grape-sugar + fructose.
Milk-sugar (lactose) = grape-sugar + galactose.
Maltose = grape-sugar + grape-sugar.

By boiling with acids and by inverting ferments, these sugars, under the assumption of water, are split up into their components. They are dextrorotatory, reduce (except cane-sugar) and form phenylosazones. Lactosazone melts at 200°; maltosazone at 208°. The disaccharides do not undergo alcoholic fermentation directly.

Cane-sugar and *maltose* are important foods. *Lactose* is also an important food and is of special physiological interest because it is a specific product of the animal body, being formed by the activity of the milk-glands. It is found only in milk, has but a slight sweet taste, and is somewhat less soluble in water than the other sugars. Milk-sugar is dextrorotatory (rotatory power 52.5°). It reduces, but does not ferment with yeast, even after previous action of the invertin, which otherwise splits up the disaccharides and renders the yeast fermentation possible. On the other hand, it is split up by bacterium lactis (lactic-acid fermentation), also by the Kephir fungus, which also produces alcoholic fermentation. Through the oxidation of milk-sugar there is formed, among others, mucic acid, an oxidation product of galactose.

The **polysaccharides** are anhydrid compounds of several molecules of the simple sugars. Their general formula is $(C_6H_{10}O_5)x$, in which x is the still unknown factor by which the formula must be multiplied to obtain the real size of the molecule. In this group belong: vegetable starch (amyloses), animal starch (glycogen), dextrin, gums, and cellulose. Some of the polysaccharides are insoluble in water (cellulose); some swell up in water, forming a sticky fluid (starch, gums); some are soluble, but are not dialyzable, and are precipitated by alcohol (glycogen, dextrin). They are dextrorotatory, do not reduce (except a few dextrins), and do not ferment with yeast. Many ferments (diastase, ptyalin) and boiling with strong mineral acids change the monosaccharides, chiefly to grape-sugar. When gum is oxidized, mucic acid is formed; the oxidation of starch, glycogen, dextrin, yields saccharic acid. Most of the polysaccharides give color reaction with iodine: Starch gives blue; glycogen, brownish red; dextrin, blue or red; cellulose, after being treated with concentrated sulphuric acid, gives blue.

Of the polysaccharides, only glycogen is found in the animal body.

Cellulose is the chief constituent of wood fibre. Starch and dextrin are important foods. Gum has only a technical value. A carbohydrate, closely related to cellulose, is found in the envelopes of the Tunicates. A gum-like carbohydrate can be split off from certain mucins (animal gum).

Glycogen is chiefly found in the liver and muscles. It is formed, first of all, by the anhydrid union of several molecules of the simple sugar, chiefly of dextrose, but also of levulose and galactose. Glycogen can also be formed from proteid.

Glycogen is dextrorotatory; boiling with acids splits it up into dextrose only, hence in the formation of glycogen from levulose and galactose, these must first be changed to dextrose.

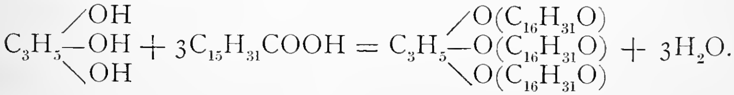
Glycogen forms an opalescent solution in water and is precipitated by the addition of half its volume of alcohol. It does not reduce nor ferment and, with iodine potassium iodide, gives a brownish-red color which disappears on heating. Ferments (diastase, ptyalin) split it up, under the assumption of water, into maltose and dextrose, dextrins being intermediate products.

The object of glycogen formation in the animal body is the storing up of carbohydrates in a form which, under the given conditions, is insoluble (like the sugar in plants is stored up as starch).

2. **Fats** are fatty acid esters of glycerin. The most important fatty acids which take part in ester formation are:

Palmitic acid, $C_{15}H_{31}COOH$;
Stearic acid, $C_{17}H_{35}COOH$;
Oleic acid, $C_{17}H_{33}COOH$.

Glycerin as a triatomic alcohol can unite with three molecules of fatty acid:



$$C_3H_5\begin{array}{l}\diagup OH\\ -OH\\ \diagdown OH\end{array} + 3C_{15}H_{31}COOH = C_3H_5\begin{array}{l}\diagup O(C_{16}H_{31}O)\\ -O(C_{16}H_{31}O)\\ \diagdown O(C_{16}H_{31}O)\end{array} + 3H_2O.$$

The glycerin-esters of palmitic, oleic, and stearic acids are called palmitin, olein, and stearin, and a mixture of these three is what is commonly known as fat.

The melting-point of stearin is 71.5°, of palmatin 62°, of olein 0°. According to the proportion of stearin and palmatin on the one hand and olein on the other, the natural fats are solid at ordinary temperature, as tallow and butter, or liquid, in which condition they are called oils.

In small quantities there are present in animal fats the glycerides of butyric acid, $C_4H_8O_2$, caproic acid, $C_6H_{12}O_2$, caprylic acid, $C_8H_{16}O_2$, capric acid, $C_{10}H_{20}O_2$, and myristic acid, $C_{14}H_{28}O_2$.

Fats are insoluble in water and cold alcohol, but readily soluble in hot alcohol and in ether. Stearin and palmitin solidify in needle-shaped crystals. On heating, especially with the anhydrid of phosphoric acid, the fats, in contradistinction from free fatty acids, yield the offensive-smelling acrolein, a decomposition product of glycerin. The fats are stained black by osmic acid. By boiling with alkalies, especially in alcoholic solutions, also by the action of many ferments (steapsin of the pancreatic juice) they are split up, under the assumption of water into glycerin and free fatty acids. The fatty acids unite with the alkali present, forming salts of fatty acids, the soaps (sodium soap or hard soap, potassium soap or soft soap).

If the fats contain free fatty acid (rancid fats), they can, on melting, form an emulsion with water and a little soda; in this process of emulsion the fats are finely divided, forming a milky fluid. As emulsification is dependent upon the presence of soap, formed by the union of fatty acid and alkali, a purely neutral fat cannot be emulsified. The emulsification of fat is of importance in the absorption of fat in the food.

Fats are found in all parts of the body, generally stored up in cells. The percentage of fat in the tissues varies very much, as it is dependent upon the state of nutrition. In lean meat there is but little above 1% fat, while the quantity of fat in a fattened animal may be above 30%. The tissues containing the most fat are the subcutaneous tissue, the mesentery, the bone marrow (adipose tissue), which may contain about 80% fat.

The physiological functions of fat are:

(*a*) By their physiological combustion they are a source of heat and force.

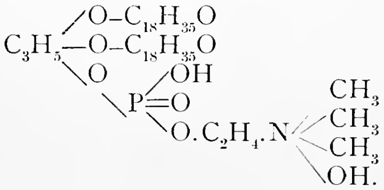
(*b*) Being poor conductors of heat, they shield the body from rapid cooling.

(*c*) They serve as protective coverings for delicate organs (eyes, kidneys).

Cholesterins are isomeric monatomic alcohols of unknown constitution, having the empirical formula $C_{26}H_{47}(OH)$. They crystallize in rhomboid tables, are insoluble in water, but readily soluble in hot alcohol and ether. Moistened with concentrated sulphuric acid and a little iodine solution, the cholesterin crystals become blue, green, and red. A solution of it in chloroform is colored blood-red by concentrated sulphuric acid. Cholesterins are found in all parts of the organism, chiefly in the brain and nerves, also in the bile. With fatty acids they form esters, capable of saponification with alkali and found in small quantities throughout the whole body. The physiological function of cholesterin is not known; its ester (lanolin) protects the skin and hairs, for which, as it does not become rancid, it is well adapted.

Lecithins are ester-like compounds of glycero-phosphoric acid with two fatty acid radicles on the one hand and of an ammonia base, cholin, on the other. Cholin is trimethyl-oxyethyl-ammonium-hydroxide. From cholin we obtain, by reduction, neurin, and by oxidation, muscarin. Neurin and muscarin are poisons, cholin is not.

The most common lecithin, stearic acid lecithin, is di-stearyl-glycero-phosphoric acid trimethyl-oxyethyl-ammonium-hydroxide:



Lecithin is insoluble but swells up in water, forming the so-called myelin figures. It is soluble in ether and alcohol, has the consistency of wax and yields imperfect crystals only at a very low temperature. Boiled with acids and alkalies, it splits up into fatty acid, phosphoric acid and cholin.

Lecithin, no doubt partly united with proteid, is a constituent of all animal cells. It is present in large quantities in the brain, spinal cord, and yolk of birds' eggs.

Protagon, a substance containing phosphorus and nitrogen (constitution unknown), is a constituent of nerves and yields similar decomposition products as lecithin. It can be extracted from the brain by 85% cold or 45% warm alcohol and is thrown down as crystals when cooled to 0°. It swells up in water, forming an opalescent solution and is soluble only in warm alcohol and in ether. At 50° C. it is decomposed, giving rise to the following glucoside-like cerebrins free from phosphorus: cerebrin, homocerebrin, encaphalin. The cerebrins, boiled with dilute sulphuric acid, yield galactose and a fat called cetylid.

Jecorin, a glucoside-like body containing phosphorus, appears to be related to protagon. It is found in the liver and other organs.

The physiological significance of these substances is not known.

To the fatty bodies also belong a few coloring compounds, stored up in the body as pigments, called chromophane and lipochrome.

3. **Proteids.**—The term proteid is here used in its widest sense; it also includes the proteid-like bodies (albuminoids) which are not regarded as real proteids by many authors.

(*a*) *Composition of Proteids.*

Proteids all contain: carbon 50–55%, hydrogen 6.5–7.3%, nitrogen 15–17%, oxygen 19–24%, sulphur 0.3–2.4%.

Besides these, there are present phosphorus, iron, calcium, magnesium, potassium and sodium; but these are not necessary constituents of proteids, for they are united, either alone or with other elements, to the already independent proteid molecule.

Nearly all proteid bodies contain a small amount of mineral constituents which, on incineration, remain behind as the ash. These are not present as impurities, but are chemically united with the proteid.

Nothing is known for certain about the constitution, molecular weight, and empirical formula of proteid. It is certain that the proteid molecule is very large.

The most reliable statements on this subject are concerning the crystallized serum albumin of the horse, which is supposed to have a molecular weight of 17,070 and the empirical formula $C_{755}H_{1215}N_{195}S_{10}O_{235}$. This number is calculated from the amount of sulphur The sulphur of most proteids exists in two forms:

1. *Easily split off by hot alkali ; with lead acetate it forms lead sulphide : reduced sulphur.*
2. *Firmly bound to the proteid molecule, only demonstrable as sulphuric acid after the decomposition of the proteid: oxidized sulphur.*

Such proteids must contain at least two atoms of sulphur.

In serum albumin the proportion between the firmly and the loosely combined sulphur is as 2 : 3: the molecule, therefore, contains at least five atoms of sulphur. This number must be doubled as the serum albumin splits up into at least seven digestion-products which contain sulphur; of these, three contain sulphur in both forms. With ten atoms of sulphur in the molecule the calculations from the elementary composition [$C = 53.08\%$; $H = 7.12\%$; $N = 15.93\%$; $S = 1.875\%$; $O = 21.995\%$] furnish us with the above formula. According to the method of determining the freezing-point, the molecular weight of 15,000 has been assigned to egg albumin.

(*b*) *The Decomposition Products of Proteids.*

By boiling with alkalies or acids and by putrefaction, proteids are decomposed. The decomposition products are:

1. If the decomposition is long continued: ammonia, carbon dioxide, acetic acid, oxalic acid, phenol, indol, skatol.
2. If the decomposition is not continued for a long time: amido acids and hexo-bases.

The following are the most important **amido acids:**

Glycocoll, amidoacetic acid, $NH_2.CH_2.COOH$, is found chiefly among the decomposition products of gelatin.

Leucin, amidocaproic acid, $C_4H_9.CH(NH_2).COOH$, crystallizes in radially striated spheres.

Tyrosin, oxyphenol-amidopropionic acid,

$$OH.C_6H_4.CH_2.CH(NH_2).COOH,$$

crystallizes in rosette-like clusters and is colored red by Millon's fluid.

Aspartic acid, amidosuccinic acid,

$$COOH.CH_2.CH(NH_2).COOH,$$

is extensively found as the amid (asparagin), in plants.

The **Hexo-bases,** lysine, arginine, and histidine, are nitrogenous substances having strong basic properties, and containing six atoms of carbon in each molecule. Some substances, containing no sulphur, are composed of hexo-bases and give real proteid reactions. These substances are therefore regarded as the simplest proteids and are called protamine. From arginine urea may be obtained by boiling with baryta water, proving that urea may be formed from proteids by a simple process of splitting up.

By means of putrefaction, other products may also be formed which are not simple decomposition products of the proteid, but which must be regarded as metabolic products of the bacteria causing the putrefaction. These products are called *ptomains*, some of which are very poisonous.

Potassium-permanganate oxidizes proteids to *oxyprotosulphonic acid*, which has still the character of a proteid but contains more oxygen and the sulphur in a completely oxidized form.

Because of their decomposition products and their relation to acids and bases with which they form salt-like combinations, the proteids may be considered as condensation products of various, in part aromatic, amido acids. Otherwise nothing is known as to their chemical constitution.

(*c*) *Physical Properties of Proteids.*

Most proteids are soluble in water or dilute salt solutions, but insoluble in alcohol and ether.

They are levorotatory.

They dialyze (except peptone) with difficulty or not at all through animal and vegetable membranes.

They do not readily crystallize. Crystals have, however, been obtained from hæmoglobin, vitellin, egg and serum albumin, and from many vegetable proteids.

The fact that crystallizable proteids do not dialyze contradicts the old classification of crystalloid and colloid bodies (although this had already been proven untenable). Proteids do not dialyze because their molecules are too large for the pores of the membranes.

(*d*) *Reactions of Proteids.*

A. **Precipitants of proteids.**

1. Many proteids are rendered insoluble by heat: they *coagulate*.

The coagulation temperature lies between 50° and 80°. The exact temperature does not only depend on the nature of the proteid but also on the concentration, the amount of salts present, and the reaction of the solution. In strongly acid or alkaline solutions, coagulation does not occur.

The coagulation does not produce any real change in the nature of the proteid; probably only an anhydrid condensation or polymerization takes place. Coagulated proteid contains less ash than non-coagulated proteid; hence by coagulation a part of the mineral constituents of the proteid is split off.

2. Many proteids are precipitated by *alcohol.* If the action of the alcohol is allowed to continue, the precipitated proteid is coagulated.

3. Nearly all proteids are precipitated by saturating their solutions with neutral salts (sodium chloride, magnesium, sodium, and especially ammonium sulphate). An acid reaction favors this precipitation.

The precipitation by salts is first of all due to the fact that the salts deprive the proteid of the solvent. Still, chemical action is not excluded. In using ammonium sulphate, for example, ammonia is set free, for the sulphuric acid unites with the precipitated proteid and at last causes a splitting up of the proteid.

By precipitation by salts, proteids can be obtained in crystalline form. Proteids cannot, like other substances, be crystallized by mere evaporation of the water which holds them in solution, for, in proportion as the water is evaporated, the proteids are precipitated and form a solid pellicle at the surface of the water. Hence the solution does not reach the condition of supersaturation necessary for crystallization. This can, however, be obtained by using salt as a precipitant, whereby the concentration of the salt is gradually increased either by the careful addition of the salt to the solution or by evaporation. For this purpose, sodium or ammonium sulphate is best.

4. Proteids are precipitated by concentrated mineral acids, especially by nitric acid (Heller's test). Metaphosphoric acid readily precipitates proteids, while the orthophosphoric acid does so with difficulty.

5. Proteids are precipitated by the salts of the heavy metals, copper sulphate, ferric chloride, neutral and basic lead acetate, platinum chloride, corrosive sublimate in hydrochloric acid solution. In these, the heavy metals unite with the proteids as a weak acid, forming a compound insoluble in water.

6. Proteids are precipitated by some weak organic acids or their salts in a solution of acetic acid: hydroferrocyanic acid, potassium ferrocyanide and acetic acid, tannic acid, picric acid, trichloracetic acid. In this case also compounds insoluble in water are formed, in which the proteids seem to take the part of a base.

7. Proteids are also precipitated by phosphotungstic and phosphomolybdic acids and potassio-mercuric iodide in the presence of free hydrochloric acid.

B. **Color reactions of proteids.**

1. *Xanthoproteic reaction.* Proteids boiled with strong nitric acid turn yellow, which is colored orange by ammonia.

2. *Millon's reaction.* Proteids boiled with mercuric nitrate solution containing excess of nitric acid are colored brick-red. This coloration depends upon the oxyphenyl nucleus of the proteids (as in case of tyrosin).

3. *Biuret reaction.* If to a solution of proteid, sodium hydrate and dilute copper sulphate be added, a violet or rose-red color results. Biuret, a derivative of urea, also gives this reaction.

4. *Adamkiewicz' reaction.* To a solution of proteids in acetic acid, add excess of concentrated sulphuric acid. A reddish-violet color appears.

(*c*) *Physiological Importance of Proteids.*

The albuminous bodies are the most important constituents of our body, for all tissues and organs are composed of them. Hence they are also called the proteids (from πρωτεύω). They form the chemical and physical basis of the living substance and are present in the body partly in a solution, e.g. the tissue fluids and cell saps; partly in a solid form (more or less swollen), forming the cells and tissues.

The proteids (including the albuminoids) form about one sixth of the body weight. About one half of all the proteids of the body are contained in the muscles, which are composed of about 20% proteids. The liver, spleen, and blood also contain the same percentage of proteid. The nerves, brain, and spinal cord have comparatively less proteids, only 8%. The bones contain 14% (mostly collagen); the skin contains 24% (mostly collagen); the adipose tissue contains only a small amount (hardly 3%) of proteids.

(*f*) *Classification of Proteids.*

Proteids are classified into: 1. Albuminous bodies or simple proteids; 2. Combined proteids; 3. Proteoses; 4. Albuminoids.

I. **Albuminous bodies** or **simple proteids** are the proteids in a more restricted sense of the word (native proteids) as they are found in the albumin (white) of the egg. They are soluble in water or in dilute salt solutions, are levorotatory and give all the precipitations and color reactions.

In this class belong the **albumins** and **globulins.** The albumins contain more sulphur and give a weaker xanthoproteic reaction than the globulins.

The albumins are soluble in water; most of the globulins are soluble only in a dilute salt solution. The globulins are therefore precipitated by half saturation with ammonium sulphate or by complete saturation with magnesium sulphate. The albumins are not so precipitated. The globulins, in distinction from the albumins, are precipitated from their solution by very dilute acids, even by carbonic acid.

Among the *albumins* there are *serum albumin*, *egg albumin*, *lact albumin*, *muscle albumin*. These albumins differ in their solubility, coagulation temperature, and in their specific rotatory power.

Among the *globulins* we have *serum globulin*, *egg globulin*, *fibrinogen*, *myosinogen*. From fibrinogen, a constituent of the plasma, the insoluble *fibrin*, is formed by the action of the fibrin ferment. Myosinogen, a constituent of muscles, coagulates during rigor mortis, yielding the myosin. The yolk of egg also contains a globulin-like body, *vitellin*.

With acids and alkalies, the simple proteids form **syntonin** (acid albumin) and **alkali albumin.** These are not coagulated by heat and are precipitated by neutralizing their solutions.

Syntonin, alkali albumin, and coagulated egg albumin are also called derived albumins, in distinction from the native albumins.

The simple proteids of our body are chiefly dissolved in the blood, lymph, and serous fluids, and form the material for replacing the proteid wastes in the tissues. For this purpose, these proteids are continually circulated through the body by means of the blood and lymph and are therefore called circulating proteids, in distinction from the deposited organ proteids. The circulating proteids are also called dead proteids in distinction from the living proteids of the tissues.

The term "living proteids" originated from the idea that the proteids of the living substance, because of its peculiar reactions, have different chemical properties and constitution from the unorganized proteids. That such a difference exists cannot be doubted, but what the difference is, is not known.

Recently peculiar phenomena have been observed in the plasma which have been ascribed to the action of the proteids of the plasma. These phenomena, the immuning and bactericidal action of serum proteids upon pathogenetic micro-organisms, cannot be explained by the physical and chemical properties of dead proteids and are therefore regarded as vital phenomena.

II. **Combined proteids** are compounds of simple proteids with other complex substances. They give the general proteid reactions. They are precipitated by alcohol and, if the action is continued for a long time, are coagulated by it. They are precipitated by making the solutions weakly acid, but are readily soluble in weak alkalies.

Although the substances included in this group differ greatly from each other, still they have this in common, that they are present in the tissue cells as organized proteids, or at least originate from decomposing protoplasm.

In this class belong:

(1) *Compounds of simple proteids and pigments.*

Hæmoglobin, the important constituent of the red-blood corpuscle, is composed of globin, a proteid, and hæmatin, an organic pigment containing iron. No successful analysis of human hæmoglobin has been made. Hæmoglobin of the dog has the following composition: C 54.57%; H 7.22%;

N 16.38%; O 20.93%; S 0.568%; Fe 0.336%. If hæmoglobin contained one atom of iron, the empirical formula would be $C_{636}H_{1025}N_{164}O_{181}S_{3}Fe$.

Hæmoglobin is soluble in water and crystallizes directly from its aqueous solutions in red, double-refractive prisms and needles. Hæmoglobin solutions absorb the yellowish-green light of the solar spectrum. This is characteristic of hæmoglobin and may serve for the detection of blood pigment.

Hæmoglobin is decomposed and coagulated by heating. It gives most of the proteid reactions. By boiling with alkalies and lead acetate, however, it does not yield lead sulphide.

Hæmoglobin forms more or less unstable compounds with oxygen, carbonic oxide, and nitric oxide. The compound with oxygen is called oxyhæmoglobin and is of great physiological importance.

Oxyhæmoglobin contains one molecule of hæmoglobin and one of oxygen or two atoms of oxygen to each atom of iron. The oxygen is held but feebly, for even at body temperature the oxyhæmoglobin decomposes into hæmoglobin (also called reduced hæmoglobin) and free oxygen. Oxyhæmoglobin is also reduced by putrefying substances and by ammonium sulphide.

Oxyhæmoglobin has two absorption bands in the yellow-green of the spectrum between the D and E lines. Reduced hæmoglobin has but one broad band in the yellow-green.

Methæmoglobin is a stronger union of hæmoglobin with oxygen. It is formed by the addition of potassium ferricyanide to oxyhæmoglobin; it is reduced by ammonium sulphide. It has four absorption bands, one of which, situated in the red, is very characteristic.

The compounds of hæmoglobin with carbon monoxide and nitric oxide are of interest only as they are frequently the cause of death. This is especially true of *CO-hæmoglobin.* Carbonic oxide forms a stronger union with hæmoglobin than oxygen does; it therefore drives out from the oxyhæmoglobin the oxygen which is absolutely necessary for life. A solution of CO-hæmoglobin has a cherry-red color and a spectrum similar to that of oxyhæmoglobin, but ammonium sulphide does not change its two absorption bands to the single absorption band of reduced hæmoglobin. CO-hæmoglobin gives a bright-red precipitate with sodium hydrate or with potassium ferrocyanide and acetic acid.

By acids and alkalies, hæmoglobin is broken up into its components, globin (96%) and hæmatin (4%).

Globin is a globulin-like proteid, showing all the characteristics of a proteid, but containing no sulphur which is easily split off.

Hæmatin, $C_{32}H_{32}N_4O_4Fe$, is insoluble in water, but soluble in dilute acids and alkalies and in alcohol containing ammonia or sulphuric acid. The brownish-red acid hæmatin solution has four absorption bands (like the methæmoglobins); the carmin-red alkaline solution has but one absorption band, located in the orange. By ammonium sulphide, hæmatin is reduced to hæmochromogen, which has two absorption bands in the green. Hæmatin therefore corresponds to oxyhæmoglobin; hæmochromogen, to reduced hæmoglobin.

If hæmatin is boiled with a little NaCl and acetic acid and the mixture is allowed to cool and evaporate, brown crystals, the so-called *Teichmann's hæmin crystals*, are produced. Hæmin is hæmatin hydrochloride. This reaction can be used in the detection of blood. The reaction succeeds still better if potassium iodide is used instead of NaCl; in this case the crystals are hæmatin hydroiodide.

By the action of strong sulphuric acid, hæmatin loses its iron and hæmatoporphyrin is formed. This is a red pigment and has a narrow absorption band in the orange and a broad band in the yellow-green. For the physiological importance of hæmoglobin, see Chapters II and III.

Hæmatoidin is an orange-colored pigment crystallizing in rhombic tables. It is formed from the blood pigment of old extravascular blood-clots. It is supposed to be identical with the bile pigment, bilirubin.

Melanine, a black pigment found in the body, is also supposed to be derived from the hæmoglobin.

(2) *Compounds of simple proteids and carbohydrates.*

Glyco-proteids. In this class are the **mucins** and mucous substances, found in the secretions of the mucous glands and epithelial cells of mucous membranes, and in tendons and the umbilical cord. They are insoluble in water, but, because of their acid properties, give a neutral, stringy solution with weak alkalies. They are not coagulated by boiling and are completely precipitated from salt-free solutions by acids as well as by alcohol and most of the proteid precipitants (not by nitric acid, nor by acetic acid and potassium ferrocyanide). They give all the color reactions of proteids. By boiling with acids, they split up into proteid and a polysaccharide, the animal gum. They serve to lubricate the mucous membranes, and to shield them from mechanical and chemical injuries.

(3) *Compounds of proteid with substances containing phosphorus* are **nucleins** and **nucleo-albumins.**

(*a*) **Nucleins,** so called because they were first obtained from the nuclei of fish-blood corpuscles, are divided into:

(α) *Paranucleins*, i.e. compounds of proteids and phosphoric acid.

(β) The *true nucleins*, i.e. compounds of proteids and nucleic acids which are composed of phosphoric acid and xanthin or nuclein bases.

(*b*) **Nucleo-albumins** or nucleo-proteids are compounds of nuclein and proteids. They are found in cells as the constituents of the nucleus and of the protoplasm. The chromatin of the nucleus and probably the structure of the protoplasm capable of staining, are composed of nucleo-proteids. They are insoluble in water but soluble in dilute alkalies, with which they form neutral compounds because of their strong acidity. They are precipitated by acids and, in their precipitated condition, they are coagulated by heat. They also give most of the proteid reactions. Because of their readiness to break up, it is difficult to isolate them.

By boiling with dilute acids or alkalies the nuclein is split from the nucleo-albumin and, by continued action of these reagents, this breaks up into proteid, phosphoric acid, and, eventually, the xanthin bases (xanthin, guanin, adenin, hypoxanthin, etc.), which are closely related to uric acid.

Some nucleo-proteids also contain iron, e.g. the *hæmatogen* of the egg-yolk, so called because hæmoglobin is supposed to originate from it.

The best-known nucleo-proteid is **caseinogen** of milk. It is formed during secretion by the milk-gland. It is insoluble in water, forms soluble compounds with alkalies and alkaline earths, and is split up by acids, yielding paranuclein. Caseinogen is not coagulated by boiling, but it is precipitated by weak acids. By the action of the ferment rennin it yields casein, a proteid which forms an insoluble compound with calcium.

III. **Proteoses.**—The proteoses are the products of the splitting up of the simple and combined proteids. They are formed during *digestion* of proteids or by the action of dilute acids upon proteids, and they differ but little in elementary composition from each other and from the proteids out of which they are formed. Their formation does not depend upon deep-seated chemical changes of the proteids, but only upon the splitting up of a large molecule into many similar smaller molecules, under the assumption of water. It is only in the amount of sulphur they contain that they differ from each other and from the mother-substances.

In the splitting up of simple proteids many intermediate products are formed which are called the *albumoses*, while the end-products are called *peptones*. According to their origin, the albumoses are called fibrinoses, globuloses, viteloses, caseoses, and myosinoses.

The proteoses (albumoses and peptones) are all readily soluble in water, except heteroalbumose, and many of them (peptones and some albumoses) are dialyzable. They are not coagulated by heat; alcohol precipitates them with difficulty but does not coagulate them. They are all levorotatory. The rotatory power of all the proteoses formed by gastric digestion from a simple proteid body is greater than that of the undigested proteid, but the rotatory power of the products formed by pancreatic digestion is smaller than that of the original proteid.

The proteoses give all the proteid color reactions, but not all the precipitation reactions.

The proteoses behave towards the mineral acids and bases like amido acids; the acids are simply added to the ammonia group, and the metals of the bases replace the hydrogen of the carboxyl groups.

Proteoses, like native proteids, are neutral because the acid carboxyl and the basic ammonium nucleus are both neutralized by their intimate union. Mineral acids destroy this union, the strong acid replacing the carboxyl, hence the compound formed is acid because of the free carboxyl groups. If proteoses combine with alkali, the ammonium group is set free and the compound formed has an alkaline reaction. The power of proteoses to combine with acids and alkalies is the greater the further the splitting up of the proteid has been carried; it is greatest in peptone in which the combining power is many times that of the native proteid.

The albumoses differ from the peptones not only in the size of the molecule and the percentage of suphur, but also in the precipitation by salts. *Albumoses are precipitated by saturating their solution with ammonium sulphate; peptones are not thus precipitated.*

Albumoses are divided into primary and secondary albumoses which differ from each other in their solubility. The primary albumoses (protalbumose and heteroalbumose) are precipitated from a neutral solution by saturating with NaCl. The secondary albumoses (deuteroalbumose) are thus precipitated only from acid solutions; sometimes they are not precipitated by NaCl at all.

The secondary albumoses are with greater difficulty precipitated by other reagents also; they are not precipitated by nitric acid or 2% copper sulphate solutions, and their precipitation by potassium ferrocyanide and acetic acid is slow and incomplete. The primary albumoses obtained from the crystallized serum albumin contain more firmly combined sulphur, the secondary has more loosely combined sulphur.

Judging from the freezing-point, it is supposed that deuteroalbumose has a larger molecular weight than protalbumose. Hence the deuteroalbumoses cannot be regarded as the splitting-up products of protalbumoses.

Peptones are not precipitated by any proteid precipitant except tannic and phosphotungstic acid. They are more dialyzable than the albumoses, yet their power of dialyzing is only one-fourth of that of grape-sugar. They are soluble in all proportions in water. Their solutions have a disagreeable bitter taste.

The red color which peptones give in the biuret reaction is highly characteristic of peptones, the other proteids giving a reddish-violet color.

The various peptones differ from each other in the amount of sulphur; some have loosely combined sulphur, others have only firmly combined sulphur. They also differ in their behavior towards the pancreatic ferment trypsin; the "*hemi-peptones*" are split by trypsin into leucine, tyrosine, and aspartic acid, etc.; the "*anti-peptones*" not.

Nothing is definitely known as to the number of peptone molecules formed from one molecule of simple proteid. From a molecule of crystallized serum albumin, if the calculated molecular weight, 17,070, is correct, at most ten molecules of peptones can be formed, for one molecule of serum albumin contains ten atoms of sulphur and each molecule of peptone must contain at least one atom of sulphur, since peptone must still be regarded as a proteid.

Albumoses and peptones are found only in the alimentary canal, having been produced by the digestion of the proteids of the food. By their formation, the insoluble and coagulable or at least undialyzable proteid of the food is rendered into a soluble and dialyzable form suitable for absorption.

Proteoses-like bodies are also formed from native proteids by the action of superheated steam. The products thus formed are called atmidalbumoses and atmidpeptones. They have no loosely combined sulphur and differ from the ordinary proteoses in their precipitation. Atmidproteoses are not readily absorbed from the intestine. Evidently by superheated steam the proteids are not only split up but undergo other changes which make them more or less unsuitable for nutrition.

IV. **Albuminoids** are derivatives of proteids, which still have the characteristic percentage composition of proteids, but differ from them chemically, physically, and especially physiologically. Some of the albuminoids contain more sulphur, others less, than the proteids. They do not give all the characteristic color reactions, because some do not have the aromatic groups, hence all of them do not yield tyrosin when boiled with alkalies. They do not dissolve but swell up in water. They are not coagulated by heat.

Physiologically they differ from the proteids in that they are either indigestible, or, if they can be digested and absorbed, they cannot replace the used-up body proteids as the other proteids can.

Also in regard to their functions in building up the body, there is a great difference between the albuminoids and the simple and combined proteids. The latter form the bases of the living substance, and as such are the chief constituents of the cells. The albuminoids, on the contrary, are present only as intracellular substances; they are indeed cell-products and perhaps take a part in cellular metabolism, but their chief physiological importance lies in their furnishing the material for covering and framework. They form the organic ground-substance of bones, cartilage, tendons, fasciæ, connective tissue and of the covering of the body—epidermis, hair and nails. They are the most important organic constituents which furnish form and stability to the body.

The albuminoids are specific animal products. They are formed by the cells themselves, being the intracellular substance. In the epidermal cells all the protoplasm is changed to a certain kind of albuminoid substance. They are formed from the proteids of the cells by chemical changes the nature of which is still unknown.

Albuminoids unite with acids and alkalies; in some of them the amido-acid character is even more apparent than in the other proteids. By digestion, albuminoids, if at all digestible, yield proteoses-like products.

Among the albuminoids are:

1. **Keratin,** the chief constituent of the horny epithelial cells, hair, nails, and of the membrane of nerves (here called neuro-keratin). It is rich in sulphur (2–5%), most of which is loosely combined so that it is easily split off by alkali. It gives all the proteid reactions and in decomposing yields tyrosin. It is not

soluble in water; in general, it is not soluble without previous decomposition. It cannot be digested.

2. **Elastin,** from the elastic fibres, has only firmly combined sulphur. It gives the color reactions of proteids and yields the corresponding decomposition products. It is insoluble in water and can be digested by pancreatic juice, not by gastric juice.

3. **Collagen** forms the greater part of the albuminoids found in our body. It forms the fibres of the connective tissue and the organic basis of bones and cartilages. It contains no loosely combined sulphur, does not give Adamkiewicz's and Millon's reactions, neither does it yield tyrosin when decomposing, hence it contains no aromatic group. It contains a little more oxygen than the proteids, hence it is perhaps formed from proteids by oxidation.

If collagen is boiled for a long time in water, it takes up water and, on cooling, a solid jelly called **gelatin** is formed. If gelatin is heated to 130° it again changes to collagen. Gelatin is the hydrate of collagen. It is soluble in hot but not in cold water (the reverse of native proteids); in cold water it only swells up.

Gelatin is not precipitated by mineral acids, by potassium ferrocyanide and acetic acid, nor by salts of heavy metals (except mercuric chloride in hydrochloric acid). It is, however, precipitated by salts. It gives the biuret and xanthoproteic test.

Gelatin is digested with difficulty by pepsin but readily by trypsin, gelatoses and gelatin peptones being formed. Concerning the importance of gelatin as a food see Chapter VIII.

4. **Chondrin** is a mixture of gelatin and chondroitin-sulphuric acid which is an ethereal sulphate of chondroitin, a nitrogenous derivative of carbohydrates; it can be isolated from cartilage by dilute alkalies. If bones are boiled with dilute mineral acids, the chondroitin yields acetic acid and the nitrogenous chondrosin. Chondrosin reduces cupric oxide in alkali solutions, and by boiling with barium hydrate yields glycuronic acid and glucosamine.

Ferments. — Among the proteid-like bodies are also counted the unformed ferments. The composition of the ferments is unknown, but they have some properties in common with proteids. They are soluble in water and glycerin, are precipitated and partly coagulated by alcohol, can be precipitated by salts, are not dialyzable, and give the proteid color reactions. They are products of cellular activity.

The unformed ferments here referred to are to be distinguished from the formed ferments which are organisms (bacteria, fungi,) which, by contact, split up certain substances (e.g. yeast, bacterium lactis. See page 20).

Their most important property is that, in very small quantities, they can chemically change unlimited quantities of certain substances, without suffering any chemical change themselves. Their action, in general, consists in a hydrolytic splitting up of the large molecule into smaller molecules and in transforming the chemical potential energy into kinetic energy. Their action depends upon the reaction and concentration of the solution of the substances upon which they act. The more concentrated the solutions, the less active are the ferments. They are rendered inactive by heating.

Ferments are classified as:

1. Coagulative ferments, which split up certain soluble proteids into an insoluble and soluble part (e.g. the coagulative ferment of blood, rennin of the stomach, myosin ferment).

2. Digestive ferments, which, by hydrolytic splitting up, change the insoluble or soluble proteid of food not capable of absorption into a soluble form capable of absorption. These include:

(*a*) Diastatic ferment (in saliva and pancreatic juice), which changes starch to sugar.

(*b*) Proteolytic ferment (in gastric and pancreatic juices), which changes simple proteids to proteoses.

(*c*) Stereolytic ferment (in pancreatic juice) which split neutral fats into fatty acids and glycerin.

Concerning the action of these ferments in detail, consult the proper section in special physiology.

3. END-PRODUCTS OF METABOLISM

To this class belong the substances which are formed by the combustion of the energy-yielding substances of the body (proteids, fats, carbohydrates). These products are excreted from the body.

It is possible and even probable that the end-products of metabolism are not formed directly by combustion from the body-substance, but that a series of intermediate substances are formed. But nothing is known concerning these intermediate products; everything that has hitherto been said about them is based on mere assumption. We must therefore be satisfied with enumerating the end-products.

Among the end-products we may, in the first place, name the already mentioned **water** and **carbon dioxide,** the chief combustion products of all organic substances.

In abnormal conditions, organic substances of carbon, hydrogen and oxygen which can still undergo oxidation are excreted from the body. These are, evidently, products of incomplete combustion. Such substances are:

1. Lactic acid, $C_3H_6O_3$. There are three lactic acids.

(*a*) Ethyline lactic acid, $CH_2OH.CH_2.COOH$, is present in the body in but very small quantities.

(*b*) Ethyliden lactic acid, $CH_3.CHOH.COOH$. Of these there are two:

(1) The optically inactive fermentation lactic acid, formed by the lactic-acid fermentation of carbohydrates.

(2) Dextrorotatory sarcolactic acid, found in the muscles and in urine.

Sarcolactic acid is a syrupy fluid, soluble in water, alcohol and ether. It forms a characteristic crystallizable salt with zinc; this is of use in isolating the sarcolatic acid.

Lactic acid is present in the urine if the supply of oxygen is deficient (dyspnœa).

2. β-oxybutyric acid, $CH_3.CHOH.CH_2.COOH$, diacetic acid, $CH_3.CO.CH_2.COOH$, and acetone, $CH_3.CO.CH_3$, appear in the urine in certain diseases, especially diabetes. Acetone is present in normal urine in very small quantities.

3. It may here be mentioned that oxalic acid, $COOH.COOH$,

is present in small quantities in the urine (in the form of calcium oxalate, yielding the "envelope crystals").

While the combustion of fats and carbohydrates yields only CO_2 and H_2O, combustion of proteids furnishes these and a series of other products which contain the nitrogen, sulphur, and phosphorus of the proteid. These products are of importance in estimating the extent of proteid metabolism.

By the combustion of the proteid, its sulphur and phosphorus form *sulphuric* and *phosphoric* acids, which are excreted in the form of salts.

The *nitrogenous end-products* of metabolism can unite with still more oxygen; hence, in the physiological combustion of proteids, the proteids are not fully oxidized, but an oxidizable residue is left which cannot be used in the body. The nitrogeneous end-products are:

1. **Ammonia,** excreted in small quantities as ammonia salts.

2. **Urea,** $CO(NH_2)_2$, the diamid of carbonic acid or carbamid.

Urea crystallizes in colorless needles or long, rhombic prisms; it is neutral and has a cool saltpetre taste. It melts at 130–132° C., but in solutions undergoes decomposition at 60–70° C. It is soluble in water and in alcohol, but not in ether.

Decomposition of urea.—On heating, dry urea forms ammonia and biuret. Two molecules of urea form one molecule of biuret and one of ammonia.

$$2CO(NH_2)_2 = NH_2.CO.NH.CO.NH_2 + NH_3.$$

Biuret gives a reddish-violet color with copper sulphate and potassium hydrate (origin of the term biuret reaction).

By heating with baryta-water, alkalies, and by the action of certain micro-organisms (during alkaline urine fermentation) urea takes up water and forms ammonium carbonate.

An alkaline solution of sodium hypobromite decomposes urea into carbon dioxide, water and nitrogen:

$$CO(NH_2)_2 + 3NaOBr = 3NaBr + CO_2 + 2H_2O + N_2.$$

Compounds of urea.—With many acids and bases, urea forms characteristic compounds. The acids unite with the ammonia group, in which the nitrogen becomes quinquivalent. The most important compounds are:

(*a*) Urea nitrate, $CO(NH_2)_2.HNO_3$. It crystallizes in smooth, hexagonal, colorless platelets, soluble in pure water but soluble with difficulty in water containing nitric acid. The crystals are obtained by adding an excess of strong nitric acid to a concentrated solution of urea. The compound serves for the detection and isolation of urea.

(*b*) Urea oxalate, $[CO(NH_2)_2]_2.C_2H_2O_4$.

(*c*) A white precipitate is formed when a urea solution is mixed with a solution of mercuric nitrate. The proportion in which urea and mercuric nitrate unite varies with the concentration of the urea and the mercuric nitrate used. Upon the precipitation of urea by mercuric nitrate depends Liebig's titration method for estimating urea.

Synthesis of urea.—Urea is formed:

1. By heating ammonium cyanate:

$$NH_4.O.CN = CO(NH_2)_2. \quad \text{(Wöhler, 1828.)}$$

2. By heating ammonium carbonate with metallic sodium, water being split off.

3. By passing an alternating electrical current through a solution of ammonium carbamate, $NH_2.COONH_4$, water being split off from the ammonium carbamate.

4. From carbonylchloride and ammonia:

$$COCl_2 + 2NH_3 = CO(NH_2)_2 + 2HCl.$$

5. From ethyl carbonate and ammonia:

$$CO_3(C_2H_5)_2 + 2NH_3 = 2(C_2H_5.OH) + CO(NH_2)_2.$$

Presence and formation of urea in the animal body—Urea forms most of the solids of the urine of mammals. It is present in small quantities in the blood, in all tissue fluids, and in many organs of the body.

Urea is the most important nitrogenous end-product of proteid combustion. Other nitrogenous end-products are present in but small quantities. The amount of urea excreted depends, therefore, upon the extent of proteid metabolism.

A large portion of the urea is formed in the animal body synthetically from the combustion products of proteids, namely, carbon dioxide and ammonia. That this formation is possible is proven by the following facts:

Certain ammonia salts, especially ammonium carbonate, introduced into the body do not appear in the urine as ammonia salts, but the amount of urea is increased in proportion to the ammonia salts taken. This is also true for some substituted ammonia compounds, such as amido acids (leucine, glycocoll, tyrosine and others).

That the ingested ammonia salt is really changed to urea and does not merely increase proteid decomposition and thus the excretion of urea, is proven by the fact that if a substituted ammonia salt is ingested, the corresponding substituted urea is formed. If meta-amido-benzoic acid, $NH_2.C_6H_4.COOH$, is ingested, we find uramidobenzoic acid, $\mathbf{NH_2.CO.N}H.C_6H_4.COOH$.

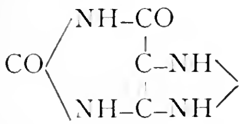
The place where the synthetical formation of urea from ammonia takes place is the liver. If defibrinated blood containing ammonium carbonate is passed through an excised liver, into the portal vein and out of the hepatic vein, the ammonium carbonate decreases, while the urea increases, in the blood. If the liver is artificially cut off from the circulation, the amount of urea is decreased, while the amount of ammonia and also of amido acids (leucine, tyrosine) in the urine is increased. This is also true for many diseases of the liver.

The nature of the substituted urea shows the part played by the carbamic acid in urea formation. Perhaps carbamic acid and ammonia are formed by the proteid metabolism and that these substances are changed to urea in the liver. Hence urea must be regarded as the amid of carbamic acid.

The object of the formation of urea from ammonia salts seems to be to change the injurious ammonia formed by proteid metabolism into a harmless compound.

It is a question, however, whether all the urea formed in the body is derived from ammonia or ammonia derivatives. It is probable that some of the urea can also be directly split off from the proteid.

3. **Uric acid,** $C_5H_4N_4O_3$, has the structural formula:



[Diureid of trioxyacrylic acid.]

Pure uric acid crystallizes in colorless, rhombic prisms, but directly from the urine it yields bundles of colored dumb-bell and whetstone crystals. Uric acid is but slightly soluble in cold water (0.05 g in one liter); it is a little more soluble in hot water (0.5 g in one liter) or in the presence of urea; it is insoluble in alcohol and ether. As a dibasic acid it forms neutral and acid salts. The neutral alkali salts are quite soluble in water; the acid salts are also more soluble than the free acid. But these are precipitated even by the cooling of the urine and, as they take with them the pigments of the urine, they form reddish precipitates (sedimentum lateritium).

The salts of uric acid with the alkali-earths, most of the metals, and also ammonia are not very soluble in water.

Because of the comparative insolubility of uric acid, it is easily deposited in the kidneys, ureters and the tissues of the body (gravel, gout).

If uric acid to which nitric acid has been added is evaporated to dryness and to the residue ammonia is added, a reddish-violet color results which gives place to a bluish violet on addition of sodium hydrate (*murexide test* for uric acid).

By careful oxidation of uric acid, allantoin and carbon dioxide are formed: $C_5H_4N_4O_3 + O + H_2O = C_4H_6N_4O_3$ (allantoin) $+ CO_2$.

Allantoin is found in the allantoic fluid and in the urine of newly born mammals. On oxidation it yields urea and oxalic acid: $C_4H_6N_4O_3 + O + 2H_2O = 2CO(NH_2)_2 + C_2O_4H_2$.

Uric acid can be formed synthetically:

(*a*) By melting urea and glycocoll together:

$$3CO(NH_2)_2 + NH_2.CH_2COOH = C_5H_4N_4O_3 + 3NH_3 + 2H_2O.$$

(*b*) From urea and trichlorlactamide:

$$2CO(NH_2)_2 + C_3Cl_3O_2H_2NH_2 = C_5H_4N_4O_3 + ClNH_4 + H_2O + 2HCl.$$

Presence and formation of uric acid in the animal body.—Uric acid is found in small quantities in the urine, also in the blood and the organs of the mammals. It is the chief constituent of the urine of birds and reptiles. It is formed, like urea, from the decomposed proteids. In the liver of birds, uric acid appears to be formed synthetically from lactic acid and ammonia salts. If the liver of a bird be extirpated, the urine contains lactic acid and ammonia salts instead of uric acid. Urea and amido acids given to birds is excreted in the form of uric acid. Whether in mammals uric acid is also formed synthetically is not known.

Uric acid is closely related to the nuclein bases; by reduction it can be changed to xanthin and hypoxanthin (see below). Hence it is formed in the animal body probably by the splitting up and oxidation of the nucleins.

It is supposed that the uric acid is especially formed from the nucleins of the nuclei of the decomposed leucocytes. This is based upon the facts that large increase and greater destruction of leucocytes in the blood (leukæmia) is accompanied by greater excretion of uric acid, and that by heating the pulp of spleen or a boiled aqueous extract of spleen with blood, uric acid is formed. In this, however, the oxidizing power of the blood is necessary.

The excretion of uric acid is increased by food rich in nucleins. Uric acid introduced into the body of a mammal is, for the greater part, excreted as urea.

4. **Nuclein or xanthin bases.** These are:

(*a*) Guanin, $C_5H_5N_5O$.

(*b*) Xanthin, $C_5H_4N_4O_2$.

(*c*) Adenin, $C_5H_5N_5$.

(*d*) Hypoxanthin, $C_5H_4N_4O$.

These substances are closely related to each other. Hypoxanthin is an oxidation product of adenin, xanthin is an oxidation product of guanin and of hypoxanthin. They are regarded as the precursors of uric acid or urea, for by the reduction of uric acid xanthin and hypoxanthin can be produced. They are formed by the splitting up of nucleins (see page 35).

They are found in small quantities in urine, blood and the organs, especially the liver and spleen. Their excretion is increased during leukæmia.

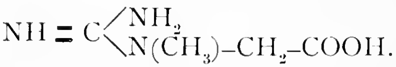
5. **Hippuric acid** (Benzoylglycocoll),

$$C_6H_5.CO.NH.CH_2.COOH,$$

is found in the urine of plant-eaters. It is formed in the kidneys by the synthesis of benzoic acid, $C_6H_5.COOH$, and glycocoll, $NH_2CH_2.COOH$.

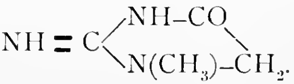
6. **Kreatin** and **kreatinin.**

Kreatin, $C_4H_9N_3O_2$, is methylguanidin-acetic acid:

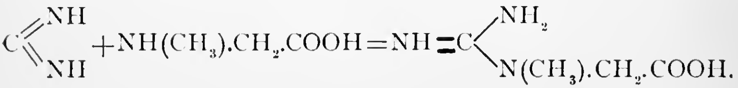


Guanidin is imido-urea: $NH = C(NH_2)_2$.

Kreatinin, $C_4H_7N_3O$, is the anhydrid of kreatin:



Kreatin can be synthetically formed from cyanamid and methylglycocoll (sarcosin):



Kreatin and kreatinin crystallize in monoclinic prisms. Both are soluble in water. The reaction of kreatin is neutral, that of kreatinin, alkaline. By the action of alkalies both form decomposition products, among others, urea.

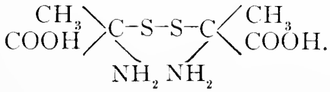
If to an alkaline solution of kreatinin a few drops of sodium nitroprusside are added, a red color is produced which soon disappears (Weyl's kreatinin test). This color is not brought back by the addition of acetic acid, like that of aceton. Kreatinin unites with zinc chloride, forming kreatinin zinc chloride, a slightly soluble, double salt which readily crystallizes.

Kreatin is found in the blood and in many organs, especially in the muscles. It is regarded as a precursor of urea. Kreatinin is a constituent of urine.

It is a question whether the kreatinin of urine is formed from the kreatin of the muscles. The amount of kreatin in the muscles is said to be increased by muscle activity, not so the kreatinin of the urine. On the other hand, it has been observed that kreatin fed to animals increases the amount of kreatinin in the urine correspondingly.

Carnine, $C_7H_8N_4O_3$, is also a constituent of muscles. By oxidation with nitric acid it is changed to hypoxanthin.

Cystin, a nitrogenous body found in urine during pathological conditions (increased putrefaction in the intestine, diseases of intestine), is the disulphide of amido-ethylidene lactic acid:



$$\begin{matrix}CH_3\\COOH\end{matrix}\!>\underset{NH_2}{C}-S-S-\underset{NH_2}{C}<\!\begin{matrix}CH_3\\COOH.\end{matrix}$$

Cystin is of interest because in it sulphur is excreted from the body in unoxidized form.

7. **Bile acids** are the union of a nitrogenous with a non-nitrogenous acid. The nitrogenous part is an amido-acid (glycocoll or taurin); the non-nitrogenous part is a cholalic acid (or fellic acid).

The bile acids are soluble in water and alcohol but insoluble in ether. They are precipitated in crystalline form from the alcoholic solution by ether. They give a cherry-red color with furfurol, or cane-sugar, and concentrated sulphuric acid (Pettenkofer's test). They are monobasic acids which form salts with alkalies. These salts are dextrorotatory.

In human bile there are:

(*a*) **Glycocholic acid,** $C_{26}H_{43}NO_6$, a compound of glycocoll and cholalic acid.

(*b*) **Taurocholic acid,** $C_{26}H_{45}NSO_7$, a compound of taurin and cholalic acid.

Cholalic acid, $C_{24}H_{40}O_5$, is a monobasic acid with three –OH–groups (trioxy-acids). It is an unsaturated compound since it unites directly with bromine. Its constitution is unknown, as is also its origin in the body. Its high percentage of carbon makes it probable that it is first formed by synthesis.

Beside cholalic acid, there is present in the human bile another non-nitrogenous constituent of the bile acids—*fellic acid*, $C_{23}H_{40}O_4$. In animals there are still other non-nitrogenous constituents of bile acids, closely related to cholalic acid.

Glycocoll (amido-acetic acid), $NH_2CH_2.COOH$, is a decomposition product of proteids. It is especially present among the products of the splitting up of gelatin.

Taurin (amido-ethylsulphonic acid), $NH_2.C_2H_4.SO_2OH$ (the sulphur is directly united with the carbon, hence a sulphonic acid), may also be regarded as a metabolic product of proteid.

The bile acids are formed in the liver and secreted in the form of sodium salts. They are, in part, absorbed from the intestine, in part they are transformed into their anhydrids (dyslysins) by putrefaction in the intestine. The bile acids aid the absorption of fats in the intestine (see Chapter X).

8. **Bile pigments.**—The most important are:

(*a*) **Bilirubin,** a reddish-yellow pigment, $C_{32}H_{36}N_4O_6$.

(*b*) **Biliverdin,** a green pigment, $C_{32}H_{36}N_4O_8$.

Biliverdin is an oxidation product of bilirubin. The bile pigments are weak acids, forming soluble salts with the alkalies and insoluble salts with calcium (this last is found in the gall-stones).

Bilirubin is slightly soluble in alcohol, readily in chloroform, and crystallizes in rhombic tables. Biliverdin is readily soluble in alcohol, slightly in chloroform. Bilirubin, by the reduction of nascent hydrogen, takes up water and forms *hydrobilirubin*, $C_{32}H_{40}N_4O_7$, which is identical with *urobilin* (a pigment of urine). Urobilin cannot be changed back to bilirubin by oxidation.

Gmelin's test.— In a test-tube place some nitric acid containing nitrous acid. Carefully cover it with an aqueous solution of bile pigment. At the junction of the two liquids, colored layers will be seen, which from the top downward are green, blue, violet, red, reddish yellow. The pigments to which the colors are due are formed by the oxidation of bilirubin or biliverdin; they represent various oxidation stages of the bile pigment.

The bile pigments are made in the liver from the hæmatin formed by the decomposition of the red blood corpuscles. This hæmatin loses its iron:

$$C_{32}H_{32}N_4O_4Fe\text{ (hæmatin)}+2H_2O-Fe=C_{32}H_{36}N_4O_6\text{ (bilirubin)}.$$

9. Besides the end-products of metabolism above named, there are present in the urine aromatic substances. It is not certain whether these originate by metabolism or whether they are merely products absorbed from the alimentary canal. By the proteid putrefaction in the intestine, aromatic compounds are formed (phenol, aromatic oxyacids, indol, skatol) which, in so far as they are not cast out with the fæces, are absorbed by the body and are in part oxidized (forming indoxyl, skatoxyl) and in part united with sulphuric acid and excreted by the kidneys as such. For further information, see Chapter VII and Chapter IX.

CHAPTER II

THE BLOOD

BLOOD is a red, opaque, salty fluid, having a characteristic smell and a specific gravity of 1.053–1.066. It has an alkaline reaction, the alkalinity being equal to that of a 0.2–0.4% sodium carbonate solution.

The blood circulates through the entire animal body in a closed system of vessels which is exceedingly ramified. The most important physiological import of blood is to carry foodstuffs to the organs and to remove the metabolic products.

Blood is composed of a clear yellowish fluid, the *plasma*, in which are suspended the solid constituents, the *red and white blood corpuscles*. Histologically considered, blood is a tissue with a liquid intercellular substance.

Blood coagulates within a few minutes after leaving the vessels, i.e. it clots to a jelly-like mass. The coagulation depends upon the separation of a proteid from the plasma, the fibrin, which forms a fibrous mass inclosing the blood corpuscles in its meshes. Gradually the clot shrinks, thereby pressing out a clear, faintly yellowish fluid, the blood serum. The coagulum with the inclosed corpuscles is called the clot. Plasma is composed of serum and the fibrin-forming proteid. Serum is plasma without its fibrin-forming proteid. Blood from which the fibrin has been removed by whipping (e.g. with a rod) is called defibrinated blood, and is composed of serum and corpuscles. In whipping blood, the fibrin clings to the rod.

The quantity of blood in man is about 7.5% of the body weight, hence adult man has about five liters of blood, of which about 35% vol. is blood corpuscles and 65% vol. plasma.

1. THE BLOOD CORPUSCLES

1. **The red blood corpuscles** of man are soft, elastic, biconcave disks with circular outlines. They are 7–8μ in diameter, 1.6μ thick, have a volume of 72μ^3 and a surface of 128μ^2. In thin layers they are yellowish green, in thicker layers red; they are heavier than the plasma and therefore sink to the bottom when blood is allowed to stand.

Man and most mammals have round, non-nucleated red blood corpuscles; birds, reptiles, amphibians and fishes have oval, nucleated red blood corpuscles.

One cb.mm. of human blood contains, in the male about five, in the female about 4.5 million red blood corpuscles; their surfaces are 640 and 576 sq.mm. respectively. This immense surface favors the taking up and the giving off of oxygen in external and internal respiration. The number of blood corpuscles is found by counting the number found in an accurately measured quantity of blood diluted to a given extent. The counting is done with the aid of a microscope and a specially constructed slide.

The number of red blood corpuscles is greater the higher the altitude.

The red blood corpuscles contain 65% water and 35% solids. Of the solids the most important is

The red coloring matter of blood, **hæmoglobin,** which forms about 87–95% of the solid constituents of the blood corpuscle (11–15% of total blood); it is deposited in the framework, the stroma, of the blood corpuscles.

The hæmoglobin of the blood corpuscle becomes dissolved in the fluid of the blood by the addition of water, ether, chloroform or bile to the blood; also by decomposition, by freezing, and by thawing of the blood and by the passing through of strong electric shocks. Blood, in which the coloring is dissolved in the fluid, is transparent (laky-blood).

The cause of this dissolving of hæmoglobin in the blood fluid after the addition of water, is the disturbance of the osmotic equilibrium between the corpuscles and the surrounding fluid. The corpuscles swell by the imbibing of water and are thereby destroyed. Hæmoglobin also leaves the blood corpuscles when they are placed in the serum of another kind of animal. As such serum has all the physical properties which make the existence of the blood corpuscle possible, the cause of the passing out of the hæmoglobin must lie in the chemical difference of the various kinds of serum. These differences are due to the proteids. The proteid of one kind of serum acts upon the corpuscle of another animal as a poison (globulicidal action of the serum).

The quantity of hæmoglobin is estimated by colorimetry. A measured quantity of blood is diluted with water till it has the same color as a hæmoglobin solution of known strength; from the extent of the diluting, the quantity of hæmoglobin can be found.

For the chemical properties of hæmoglobin, see page 32.

Hæmoglobin is of physiological importance because of its power to unite with oxygen, forming a weak compound called oxyhæmoglobin; it therefore serves as the oxygen carrier (see pages 33 and 58).

The stroma of the red blood corpuscles, which remains behind after the withdrawal of the coloring matter, is composed of proteids, fat, lecithin, and cholesterin. Besides these substances, the red blood corpuscles contain salts, especially potassium chloride and potassium phosphate.

The red blood corpuscles are continually destroyed in the body in large numbers. The places of destruction are the liver and the spleen. A restitution of this loss by the formation of new corpuscles takes place in the red bone marrow (in the embryo also in the liver and spleen), the corpuscles being formed from colored nucleated blood cells, the hæmatoblasts. They are formed from these hæmatoblasts by indirect division. At first, they still contain a nucleus, but later on the nucleus disappears.

2. **The white blood corpuscles,** also called leucocytes or lymph corpuscles, are generally a little larger than the red corpuscles; they are colorless cells with one or more nuclei. They have no constant shape as they can change their form, like the amœba, and can also move about by the pushing out and withdrawing of protoplasmic processes. At rest they are spherical.

There are many kinds of leucocytes, which differ in their size and in the proportion of their protoplasm and nucleus:

1. Small cells of 4–7μ diameter with little protoplasm and one nucleus; few in number.

2. Larger cells of 7–10μ diameter with much protoplasm and one or more nuclei (large uni-nuclear and poly-nuclear cells); these make up the bulk of the leucocytes.

3. Granular cells of 8–14μ diameter, with many granules in their protoplasm; these granules stain differently in different cells. Accordingly, we speak of oxyphile (eosinophile), basophile and neutrophile cells, as the granules stain with acid, basic or neutral stains.

The number of leucocytes is about 10,000 in one cu. mm. (about 500 red to one white), but it varies greatly. The leucocytes contain besides water chiefly proteids (especially nucleins and nucleo-albumin) and in smaller quantities lecithin, cholesterin, and salts.

The white blood corpuscles are able to pass through the stomata of the walls of the capillaries and thus wander into the tissues, hence they are also called wandering cells. They are of physiological importance because they serve as transports for many undissolved substances (fat, pigment) and because they are able to destroy and remove foreign bodies (e.g. Bacteria). They migrate in large numbers from the vessels to those places where foreign substances causing inflammation are present, and there they form the pus. They are stimulated to activity by chemical action. They originate in the lymph glands and spleen (see Chapter VI).

Besides the red and white blood corpuscles, there are still other constituents in the blood having a definite form, viz.:

Blood platelets, colorless, strongly refractive disks having a diameter of $\frac{1}{3}$ or $\frac{1}{4}$ that of the red blood corpuscles. They are apparently the nuclear remains of destroyed leucocytes.

Elementary granules, i.e. fat granules, which are brought to the blood by the chyle.

2. THE BLOOD PLASMA

Pure plasma can be obtained by letting uncoagulated blood stand at low temperature (about 0° C.). By this, coagulation is prevented and the corpuscles sink and the clear supernatant fluid is the plasma.

Plasma is a yellowish, alkaline fluid, having a specific gravity of 1.03; it contains 9% solids which are:

1. *Proteids* (7–8%):

   (*a*) *Serum albumin* (3–5%).

The albumins differ from each other in their specific rotatory power, their coagulation temperature, and, as far as they are crystallizable (as in serum of horse blood), in the forms of their crystals.

   (*b*) *Serum globulin* (3–4%).

The quantity of albumin and globulin varies much. In general the albumin predominates in the blood of well-fed animals, while globulin predominates in that of fasting animals.

   (*c*) *Fibrinogen* (0.1–0.3%).

Fibrinogen is a globulin-like proteid from which fibrin is formed when blood coagulates. The amount of fibrin is but small (0.1–0.3%). Its volume, however, appears large as it is swollen. The fibrin formation is most likely brought about by the splitting of fibrinogen into two parts, one part being the insoluble fibrin, the other a soluble proteid of which little is known.

The coagulation is brought about by an unformed ferment —*thrombin*. This ferment is not present in blood in healthy blood vessels. It is formed, when blood is shed, by the breaking down of the white blood corpuscles, especially the poly-nuclear. Defibrinated blood is called *blood serum*.

As long as blood is inclosed in blood vessels having sound walls, coagulation does not occur. The coagulation of blood is prevented by cooling, by the addition of saturated salt solutions, e.g. magnesium sulphate, and by the addition of salts of oxalic, hydrofluoric, and fatty acids. Soluble calcium salts seem to aid in the formation of the coagulative ferment. The power of coagulation can also be destroyed by the injection of proteoses and of leech extract.

Coagulation is of importance in that the bleeding from vessels is stopped by the clotting of the shed blood, as the clot formed closes the opening of the vessel. In bleeders the blood does not coagulate, hence fatal bleeding is apt to occur.

2. *Ether extracts:* Fats, cholesterin, the ester of cholesterin and fatty acid, lecithin (about 5%).

3. *Carbohydrates* in the form of grape-sugar (0.1–0.2%). In the body the carbohydrates are carried in the form of grape-sugar by the blood from one place to another.

4. *End-products of metabolism* (urea, uric acid, kreatin, xanthin, lactic acid and others) in small quantities.

5. *Salts* (0.8%), chiefly NaCl (0.6%) and neutral and acid sodium carbonate; also acid calcium carbonate and magnesium sulphate in small quantities.

Alexines and *antitoxins* are proteid-like substances found in the plasma or serum and protect the body against infectious diseases. The alexines have a bactericidal action, i.e. they destroy the pathogenic micro-organisms or inhibit their action. The antitoxins render the poisonous metabolic products (toxins) of the micro-organisms harmless. The alexines are also responsible for the globulicidal action of the blood serum (see page 54).

CHAPTER III

THE GASES OF THE BLOOD AND THE CHEMISTRY OF RESPIRATION

1. THE GASES OF THE BLOOD

For the analysis of the gases of the blood, it is placed, at body temperature, in a vessel from which the air has been removed by a mercurial air-pump. The gases leave the blood, entering into the vessel; they can then be collected and analyzed.

The gases of the blood are oxygen, carbon dioxide, and nitrogen. The *oxygen* is dissolved physically to only a very small extent, the greater part being chemically united to the hæmoglobin, forming *oxyhæmoglobin*. The oxygen must be held chemically, as the quantity of the oxygen in the blood is not proportional to the partial pressure* of the oxygen upon the blood, as would be the case in a physical solution.

Oxyhæmoglobin is a compound easily undergoing dissociation; by its dissociation the oxygen is set free.

The degree of dissociation of a compound, by which a gas is set free, is dependent upon the temperature and the pressure of the gas. In a vacuum and at the body temperature, oxyhæmoglobin undergoes complete dissociation (not at 0°); in other respects, the amount of hæmoglobin chemically united with oxygen increases with the partial pressure of the oxygen, but not proportionally as in the mere physical solution.

The **carbon dioxide** of the blood is also physically dissolved to but a small extent; most of it being chemically

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* In a mixture of gases the partial pressure of one of the gases is that part of the whole pressure which the gas exerts by itself.

bound to the alkalies of the serum (chiefly to the sodium bicarbonate and, in smaller quantities, to the acid calcium carbonate). As the whole blood contains more carbon dioxide than the corresponding amount of plasma, the blood corpuscles also contain this gas in an easily dissociated form, perhaps united with the hæmoglobin or the alkali phosphate.

In a vacuum, the blood loses all the carbon dioxide not only from the acid but also from the neutral carbonates, because it contains substances of a weak acid character, which drive the carbon dioxide out of its union with alkalies. These substances are the proteids and the hæmoglobin.

The **nitrogen** of the blood is only physically dissolved. The per cent of gases in the blood is:

	Arterial Blood.	Venous Blood.
Oxygen.	19.2 vol. %	11.9 vol. %
Carbon dioxide.	39.5 "	45.3 "
Nitrogen.	2.7 "	2.7 "

These volumes of the gases are measured at 0° C. and 760 mm mercury pressure. The amount of oxygen in the arterial blood is below that of saturation. By means of violent artificial respiration, the amount of oxygen can be brought to 23%. The venous blood is not half saturated with carbon dioxide.

Arterial blood is bright red; venous blood, dark red.

The difference in color of arterial and venous blood is due to the difference in oxygen present. Artificially we can change arterial blood to dark red by taking away its oxygen (shaking with gases free of oxygen), and venous to a bright red by shaking with oxygen.

When arterial blood becomes venous, the concentration and alkalinity of the plasma are increased, for the following reasons: The red blood corpuscles swell by the inhibition of water from the plasma, leaving the plasma more concentrated. By the mass action of the carbonic acid, hydrochloric acid is set free from the sodium chloride; this hydrochloric acid enters the blood corpuscles, while the alkali carbonate remains behind. When blood is rendered arterial, the opposite takes place.

Venous blood is found in the veins (except pulmonary veins), in the right heart and in the pulmonary artery;

arterial blood is found in the arteries (except pulmonary artery), the left heart, and the pulmonary veins. The change from venous to arterial blood is brought about by the taking up of oxygen and the giving off of carbon dioxide in the lungs—pulmonary respiration. The change from arterial to venous blood is brought about by the giving off of oxygen and the taking up of carbon dioxide in the tissue—tissue respiration.

2. PULMONARY RESPIRATION

The exchange of gases between the blood and the air of the lungs depends upon the diffusion of gases through the walls of the alveoli and capillaries. This diffusion takes place from places of higher to places of lower gas pressure.

The inhaled or exhaled air contains the following gases:

	Inspired Air.	Expired Air.
Nitrogen..........	79.00 vol. %	80.0 vol. %
Oxygen...........	20.96 "	16.0 "
Carbon dioxide.....	0.04 "	4.0 "

The partial pressure at 760 mm Hg is:

	Inspired Air.	Expired Air.
Oxygen...........	152 mm Hg	122 mm Hg
Carbon dioxide.....	0.3 "	30 "

The pressure or tension of the gases of the blood is stated in terms of the partial pressure of these gases in a vessel containing the blood, necessary to keep the quantity of the gases in the blood constant. The tension is:

	Arterial Blood.	Venous Blood.
Oxygen...........	29.6 mm Hg	21.0 mm Hg
Carbon dioxide.....	22.0 "	41.0 "

The partial pressure of oxygen in inspired air is larger than its tension in the venous blood; that of carbon dioxide is less. Therefore an exchange of gases between the blood and the air in the lungs takes place by diffusion through the walls of the alveoli and of the capillaries.

According to some authors, the parenchyma of the lungs plays an active part in the giving off of carbon dioxide (in the same manner as gland cells in the secretion).

The lowest barometric pressure at which respiration of the quiet body can continue undisturbed is about 350 mm Hg.

The oxygen taken up by the blood favors the giving off of carbon dioxide because by it the carbon dioxide tension is increased, owing to the fact that oxyhæmoglobin is more acid than reduced hæmoglobin.

An adult man inhales in 24 hours about 700 g or 500 litres of oxygen and exhales 900 g or 450 litres of carbon dioxide.

The ratio of the volume of the exhaled carbon dioxide to the volume of the inhaled oxygen is called the **respiratory quotient.** Concerning its value under various circumstances see Chapter XII.

Besides the lungs, the skin also throws off carbon dioxide in small amounts (8.4 g per day).

3. TISSUE RESPIRATION

This consists of the giving off of oxygen by the blood to the tissues and the taking up of carbon dioxide. This takes place in the systemic capillaries. The giving off of oxygen takes place because the oxygen tension in the blood is greater than that in the tissues. Because of the continual oxygen consumption, the oxygen tension in the tissues is 0. The carbon dioxide formed by the combustion of the tissues accumulates to such an extent that its pressure is higher than that of the carbon dioxide in the arterial blood, hence it must pass into the blood.

The physiological combustion, by which oxygen of the blood is consumed and carbon dioxide produced, does not take place in the blood, but in the tissue. This is based on the following facts:

1. The extent of the physiological combustion is, up to a certain limit, independent of the amount of blood in the body. After a considerable loss of blood, warm-blooded animals show no change in the amount of oxygen consumed and the carbon dioxide formed, and in cold-blooded animals (frog) the physiological combustions can take place when all their blood has been taken away and replaced by an injected physiological salt solution.

2. If the processes of combustion, upon which the contraction and work of muscles depend, took place in the capillary blood of the muscle, the muscle fibre would be forced to do its work by transforming the heat, supplied to it from the blood, into mechanical work. By heating the muscle fibre, however, we are not able to obtain as powerful contractions as by physiological stimulation, if we do not use temperatures which destroy the life of the muscle (see heat-rigor, Chapter XIV). Besides this, muscles from which the blood has been removed by injecting physiological salt solutions, and even isolated muscles, can, by stimulation, be made to contract.

CHAPTER IV

CIRCULATION OF BLOOD

1. INTRODUCTION

1. If the blood is to fulfill its function of carrying materials between the organs of the body, it must circulate in the vascular system.

2. The blood flows from the left ventricle through the aorta and systemic arteries to the capillaries, and from these through the veins and right auricle to the right ventricle; thence through the pulmonary artery, capillaries, and veins and through the left auricle back to the left ventricle (Harvey, 1628).

The portal vein, formed from the capillaries of the intestine, branches again into capillaries in the liver, which in turn give rise to the hepatic veins.

3. The difference in blood pressure in the different parts of the vascular system is the cause of the circulation of the blood. The blood is driven from places of higher to those of lower pressure.

4. The differences in pressure are caused by the rhythmically contracting ventricles which, during their contraction (systole) empty their contents into the aorta and pulmonary artery and, during their relaxation (diastole), take the blood from the auricles and veins.

5. The valves of the heart prevent the regurgitation of the blood from the ventricles into the veins and from the arteries into the ventricles and thereby determine the flow of blood in one direction.

2. THE HEART

1. **The structure of the heart.**—The heart is a hollow muscle, divided by a partition into two cavities, the left and the right heart. Its cavity consists of a thin-walled auricle and a thick-walled ventricle. The muscle fibres inclose the cavities in different directions, some more or less obliquely, some in the form of the figure 8, some circularly. The walls of the left ventricle are thicker than those of the right ventricle.

At the boundary between the auricle and the ventricle are found the auriculo-ventricular valves, on the right side three (tricuspid) and on the left two (bicuspid) membranes hanging down into the ventricle. On the free edges of these membranes are the cordæ tendineæ, which are connected with the wall of the ventricle by the papillary muscles.

Between the left ventricle and the aorta and between the right ventricle and the pulmonary artery are the three pocket-like semi-lunar valves; the openings of the pockets are toward the arteries.

2. Properties of cardiac muscle.

For the investigation of the physiological properties of the cardiac muscle, the excised apex of the frog's heart is especially adapted, as this contains no ganglionic cells.

The heart muscle-fibre is cross-striated, but differs from the striated skeletal muscle in:

(*a*) Its structure. The cardiac muscle-fibres branch and anastomose with each other.

(*b*) Its functions:

α. A stimulation, if at all active, always calls forth a maximum contraction of the cardiac muscle, while a skeletal muscle does not give a maximum contraction with a weak stimulation.

β. The cardiac muscle can be thrown into tetanus only under certain abnormal conditions. If the cardiac muscle is continuously stimulated, e.g. by a constant current or by tetanizing induction shocks, generally no lasting contraction takes place (as in the skeletal); but the heart makes rhythmical single contractions which at best fuse into an incomplete tetanus (an irregular agitation and heaving of the muscle).

γ. During its contraction the cardiac muscle is not irritable (refractive) from the beginning to the maximum of the contraction. During this time a stimulation is inactive. In its relaxed condition, the cardiac muscle is again irritable; if a stimulus is introduced during this stage, a new contraction occurs which is the greater in proportion as the stimulation occurs later. When, in an independent rhythmically beating heart, such an "extra contraction" is called forth by an artificial stimulus during the diastole, the pause following upon this contraction and lasting to the next independent beat is longer than the ordinary pause between two independent beats. This lengthened pause is called the compensatory pause.

The physiological contractions of the cardiac muscle consist of single contractions which follow each other in a definite rhythm. The contraction is called *systole*, and the relaxation following upon it is called *diastole*.

The contraction of the heart begins at the mouth of the veins, from these it travels through the walls of the auricle and then through the walls of the ventricle. The whole cardiac cycle lasts about 0.86 second, which may be divided as follows:

1. Auricular systole (ventricles at rest), 0.16 second.
2. Ventricular systole (auricles at rest), 0.3 second.
3. Pause, during which both auricles and ventricles are at rest, 0.4 second.

The number of heart-beats in one minute in an adult human being is on the average 70; in children it is higher (first year 134); the number is increased by increase of temperature (fever), muscular exertion, after the taking up of food; it depends also upon mental conditions.

The contraction of the ventricular or auricular wall does not occur at all points simultaneously, but spreads itself along the cardiac muscle, like the contraction waves in the fibres of skeletal muscles. This is proven by the fact that the electrical phenomena of the stimulated cardiac muscle do not appear simultaneously at all points, so that it is possible to demonstrate, as in the striated skeletal muscle, a current of action. (See Chapter XIV.) From the results of the electrical phenomena it can also be concluded that the cardiac contraction corresponds to a twitch and not to a short tetanus.

The heart contains within itself the processes which stimulate it to its rhythmic activity, for it beats for some time after it has been cut out of the animal immediately after death. Concerning the nature of this stimulation nothing is known.

Perhaps the cardiac muscle is stimulated directly by the normal stimulus and not through the intervention of the ganglionic cells and nerve-fibres found in the walls of the heart.

In the mammalian heart the ganglionic cells lie in the auriculo-ventricular groove, in the partition between the auricles, and in the auricle near the mouth of the superior vena cava. Their function is not known.

The embryonic heart has no ganglia and yet beats rhythmically; in that case the cause of the rhythmic activity must certainly lie in the muscle itself.

Concerning the influence of the central nervous system upon the heart, see page 74.

3. The circulation of the blood in the heart.

(*a*) *In the ventricle.*—During the ventricular systole, the cavities of the ventricles are reduced in size; the blood which it contains is pressed out into the aorta and pulmonary artery. The ventricles do not completely empty themselves since, even in the strongest contraction, the cavities of the heart are not entirely obliterated.

The auriculo-ventricular valves which float upon the blood during the ventricular diastole are closed during the ventricular systole so that the blood cannot regurgitate into the auricle. When the pressure in the ventricle is increased by the systole, the blood flows behind the valves and presses their surfaces together so that they are completely closed. The valves do not bulge into the auricles because they are fastened to the papillary muscles which contract simultaneously with the walls of the ventricle.

The closure of the valves seems to follow the beginning of the systole so quickly that no blood whatever re-enters the auricle.

During the ventricular diastole the blood does not flow back from the arteries, as it accumulates in the pockets of the semi-lunar valves, pressing their surfaces together and thus closing them. The pressure in the ventricle after diastole becomes less than that in the auricle, so that now the blood flows from the auricle into the ventricle, after having opened the auriculo-ventricular valves.

(*b*) *In the auricles.*—The contraction of the auricle serves chiefly to regulate the flow in the large veins. During the ventricular systole when no blood is allowed to pass from the auricle into the ventricle, it flows from the veins into the dilating auricle. When, during ventricular pause, it is streaming into the ventricle, the auricle decreases in size proportionately to its decrease in contents.

4. The pressure in the heart.

For finding the pressure in animals, a long canula is pushed either through one of the large cervical vessels into the right auricle or ventricle, or through the carotid into the left ventricle. The canula is connected with an instrument for measuring the pressure (mercury or spring manometer). The extent of the pressure is indicated by the number of millimeters of mercury which it stands above the atmospheric pressure.

During the systole the pressure in the ventricles increases rapidly at first and then more slowly. In the left ventricle it reaches a height of 200, in the right ventricle, 60 mm Hg. During diastole the pressure sinks rapidly and may become negative, but before the next systole occurs it rises a little because of the incoming blood.

The *period of preparation* lasts from the beginning of the ventricular systole (or the closing of the auriculo-ventricular valves) to the opening of the semi-lunar valves; it amounts to 0.05–0.1 second. It can be estimated in animals by registering simultaneously the pressure in the left ventricle and in the aorta; the semi-lunar valves open the moment the ventricular pressure becomes greater than the aortic. In man, the length of this period has been found by comparing the cardiac impulse and the pulse curve.

The *period of discharge* is the period from the opening to the closing of the semi-lunar valves; during this time the ventricular pressure is higher than that of the aorta; length of period 0.18–0.20 second.

In the auricle the variations in pressure are much less than in the ventricles. During the auricular systole the highest pressure is 20 mm Hg.

5. **The cardiac sounds,** produced by the contraction of the heart, are heard when the ear is applied to the chest-wall.

The first sound, produced during the ventricular systole, is dull, lasts as long as the systole, and can be best heard over the ventricle. It depends upon the muscle tone (see Chapter XIV) and upon the vibration of the auriculo-ventricular valves produced by the sudden systolic contraction. It is still audible in the bloodless heart.

The second sound is short, clear, and most distinct over the aorta; it is caused by the vibration of the semi-lunar valves produced by their sudden closure.

6. **The cardiac impulse,** or apex beat, is synchronous with the contraction of the heart and is felt at the fourth or fifth intercostal space, about one and one-half inches to the left of the sternum. It is produced mainly as follows: the tensely contracted cardiac muscle at this point pushes forward the soft part of the intercostal space; during the relaxation of the heart, this part is pushed inward by the atmospheric pressure.

Other factors, supposed to play a part in the formation of the cardiac impulse, are the following:

During the systole, the apex of the heart is raised upward; during the discharging of the blood, upward and backward, the heart is pushed forward and downward; the arterial trunks, from which the heart is suspended, when filling are slightly twisted and when emptying untwisted from their spiral-like turning.

If a button [pelotte] is fixed upon the place of cardiac impulse, so that it is moved by the beat of the heart, and if this movement is transferred to a writing-lever, this lever will describe a curve called the *cardiogram.* This cardiogram is similar to the pressure curve of the heart, as it is, in reality, produced by the contraction of the cardiac muscle; the two curves are, however, not identical, since the cardiogram represents a pressure and volume curve.

7. **The work of the heart.**—The work which the heart does during one contraction is equal to the product of the

weight by the height to which the weight is carried. The weight lifted is that of the amount of blood sent by a single systole of the heart (pulse volume). The amount of blood thus lifted is about 66 cc., and its weight 0.07 kg. The height to which this is raised is equal to the blood pressure in the aorta or in the pulmonary artery. In the aorta the pressure is about 150 mm of mercury or about two metres of blood; in the pulmonary artery, the pressure is about one-third of that in the aorta. During one contraction, the left ventricle, therefore, does the work of 0.07 × 2 or 0.14 kilogrammetre, the right ventricle 0.047. In all, the heart in twenty-four hours does about 18,000 kilogrammetres of work.

The pulse volume is estimated by many authors as much greater (up to 180 cc) and then the work done is correspondingly greater.

In this calculation, no account is taken of the work which the heart does in imparting velocity, i.e. kinetic energy, to the blood (about 0.3 m per second). But this work is very little compared with that done to overcome the blood pressure, the former not being more than 1% of the latter.

3. CIRCULATION OF THE BLOOD IN THE VESSELS

1. **The blood pressure in the vessels.**—The blood pressure is the pressure of the blood upon the walls of the vessels, this determining the tension of the walls.

The blood pressure in the larger vessels is measured by inserting a canula into the vessel and connecting this canula with a registering manometer. The pressure can also be determined without any operation in many blood vessels of man, it being equal to the pressure necessary to close these vessels. An artery is closed when no pulse is felt peripheral to the compression. The capillary pressure is found by pressing upon a glass plate, placed on the red part of the skin, till the skin becomes pale.

The blood pressure in different parts of the vascular system varies greatly. The difference in pressure is produced by the activity of the heart and is the cause of the movement of the blood. Each particle of blood is forced from a place of higher to a place of lower pressure.

The blood pressure constantly decreases as we proceed from the aorta or pulmonary artery, through the arteries, capillaries, and veins, to the heart. The blood must consequently flow in this direction. By this movement of the blood, the difference in pressure is normally not entirely equalized, because by each succeeding ventricular systole the difference in pressure is increased.

In the aorta, the blood pressure undergoes variations of about 150 mm Hg; in the larger arteries, about 110–120 mm; in the capillaries, 24–54 mm; in the veins, only a few mm, indeed in the large veins in and near the thorax it may be a *negative* pressure of a few mm, i.e. it is less than the atmospheric pressure. On cutting such a large vein, no blood flows from the vessel, but air enters it. The cause of this negative pressure in the veins is the negative pressure existing in the thoracic cavity which is increased during inspiration (see Chapter V). The blood pressure in the pulmonary artery is about 50 mm Hg.

The blood pressure in the arteries undergoes periodic variations caused by the action of the heart; these variations are called the **pulse.** Each time that the ventricular systole sends blood into the aorta and pulmonary artery, the pressure in these vessels is suddenly increased; after this, the streaming of the blood to the capillaries causes a diminution in pressure. This periodic variation in pressure spreads itself as a **wave** throughout the whole arterial system.

The pulsatory variations in pressure are the largest in the aorta, where they amount to half of the average pressure; they become smaller in the peripheral arteries. In the capillaries and the veins there is normally no pulse.

The rate of the pulse wave (not to be confounded with the rate of the blood flow) can be found by determining the time elapsing between the beginning of the cardiac impulse and the appearance of the pulse in a peripheral artery. The rate is about six metres in one second; it depends upon the tension and the elasticity of the arterial walls. The length of the pulse wave is about 1.5 m.

If a lever is placed upon an artery so that it is moved by the pulsating artery, and if this movement is transferred to and magnified by a writing lever, a curve, the pulse curve, or sphygmogram, is produced. This curve describes more accurately the progress of the pulse. The apparatus for the production of a pulse curve is called a sphygmograph.

The pulse curve (Fig. 1) ascends rapidly and then sinks more slowly to the level of the abscissa. In the descent of the curve there is regularly found a small elevation, called the **dicrotic wave**. The cause of this wave is not fully known. Often the descending part of the curve shows still other smaller elevations which are supposed to be due to the reflection of the pulse wave in the various parts of the arterial system.

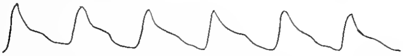


Fig. 1.—Pulse Curve (Sphygmogram) of the Radial Artery.

The blood pressure shows other periodic variations which are synchronous with the respiratory movements; the pressure sinks during inspiration and rises during expiration. This is chiefly due to the fact that during inspiration the introthoracic pressure and therefore the pressure upon the blood vessels in the thorax is diminished, while during expiration it is increased. Hence the blood vessels in the thorax are better filled with blood during inspiration than during expiration.

In general the amount of blood pressure and its pulsatory variations depend upon the state of fulness of the vessels, the tonus of the muscles of the blood vessels, and upon the number and strength of the cardiac contractions.

2. **Rate of blood flow.**—In the arteries the blood flows with a periodically accelerating rate (corresponding to the intermittent entrance of blood into the aorta); in the capillaries and veins the flow is uniform. The change from the intermittent movement of the blood in the arteries to the uniform movement in the capillaries is due to the *extensibility* and *elasticity of the arterial walls*. In vessels with rigid walls, each systole must force forward the column of blood previously pressed out of the heart. In vessels with elastic walls, the force of the systole is not directly transformed into the movement of the blood, but is first changed to the increased tension of the elastic walls, and this stored-

up energy is then gradually transformed into the energy of the moving blood. This causes the flow to be continuous.

The change of the intermittent into the continuous movement occurs, according to the same principle, in the fire-engine. The water which enters the engine periodically, leaves it in a continuous stream, being pressed out continuously by the compressed air in the air-chamber.

The average velocity decreases as we proceed from the arteries to the capillaries, and increases again from the capillaries to the veins. In the large arteries the rate is 200–400 mm per second; in capillaries 0.6–0.8 mm; in the large veins it is but little less than in the arteries. The cause of this difference is the difference in the total cross-section of the various parts of the vessels. Through each total cross-section of the vascular system there must pass in the same unit of time the same quantity of fluid, in order that the flow shall not become stationary and the blood collect in one place. Now the cross-section of the aorta and the large veins is much less than the total cross-section of all the capillaries. As the rate is equal to the volume flowing through in one second divided by the cross-section, it is evident that the rate in the arteries and veins must be greater than that in the capillaries.

The rate in the larger vessels of animals is found in the following manner. A blood vessel is cut and between the cut ends a sufficiently wide tube, the contents of which have been accurately determined, is inserted. The blood must now pass through the tube. The time taken by the blood to pass from one end of the tube to the other is then determined. For this experiment, the tube is previously filled with some indifferent fluid, which is forced from it into the vascular system by the incoming blood. According to this principle, the hæmodromometer of Volkmann is built, as is also, though more complicated, the Stromuhr of Ludwig.

In the capillaries the distance traversed by a blood corpuscle is measured directly with the aid of a microscope (e.g. in the web of frog's foot).

The pulsatory changes in the rate of the arterial blood can be investigated by the plethysmograph, an apparatus registering the changes in the pulse-volume of a limb. The changes in volume are due to the periodic increase and decrease in the supply of blood to the arteries of the limb, as the outflow of blood into the veins is uniform.

3. **The resistance to moving blood due to friction.**—The energy of the moving blood must overcome the resistance due to the friction of the particles of blood upon each other and upon the walls of the vessels. The friction is greater the smaller the cross-section of the vessel.

In a given cross-section of a blood vessel, all the parts of the blood do not move with the same velocity, but those in the middle of the vessel move faster, while those touching the walls move slowest; this is due to the resistance caused by friction. In the swifter axial current float the specifically heavier particles of the blood, the red blood corpuscles; in the slower peripheral stream are found the lighter leucocytes.

4. **Relation between fall in pressure, rate of flow and resistance.**—The energy is used for producing movement and for overcoming resistance; its consumption is the greater, the greater the movement produced and the greater the resistance overcome. The amount of energy consumed in a given length of vessel is measured by the decrease in pressure. The decrease in pressure in a unit of distance is called *the fall.*

In a tube of uniform diameter, in which the resistance offered by every cross-section is the same, and in which the rate of flow is the same at all cross-sections, the decrease in pressure is proportional to the distance traversed, i.e. the *fall* is uniform throughout. But if the fluid flows through a tube of non-uniform bore, the *fall* in the wider portions will be less than in the narrower parts, because in the wider parts the resistance is less.

The question where the fall is greatest cannot be definitely answered. In the vascular system the total cross-section increases as we proceed from the arteries to the capillaries, but the cross-section of the individual vessel decreases; going from the capillaries to the veins, it is the reverse. Now the resistance is, on the one hand, the smaller the greater the total cross-section; but, on the other hand, the greater the smaller the individual cross-section. Of these two opposing variations in resistance, the decrease predominates in the larger arteries, while the increase predominates in the veins, so that in the larger arteries the *fall* is but little; in the veins, large. In regard to the extent of the *fall* in the smaller arteries and capillaries, the evidences are conflicting.

5. **Valves in the veins.**—The circulation of blood in the veins is aided by externally compressing them, as occurs by the contraction of surrounding muscles; the regurgitation of the blood is prevented by valves, somewhat like the semilunar valves, which allow the blood to flow in the direction toward the heart only.

6. **Circulation time.**

To determine the time of a complete circulation ferrocyanide of potassium is injected into the central end of a severed vein, the time of injection being noticed. After some time the blood from the peripheral end of the cut vein is tested for the salt by being colored blue with ferric chloride. The blood has completed the entire circulation when the salt reappears at the peripheral end of the vein.

In dogs the circulation time has been found to be fifteen seconds, in man it is supposed to be twenty-two seconds.

4. INNERVATION OF THE ORGANS OF CIRCULATION

The influence of the central nervous system on the organs of circulation (heart and muscles of vessels) serves to regulate the general velocity and distribution of the blood to the different parts of the body. This is brought about by changes in the number and strength of heart-beats and by changes in the tonus of the muscles of the vessels, especially of the arteries.

1. **Innervation of the heart** (see also page 66).

(*a*) *The cardiac inhibitory nerves* are the two vagi from which fibres for the cardiac plexus are derived. Section of the vagi results in increasing the pulse frequency. The cardiac vagi are therefore continually stimulated (tonic). Stimulation of the peripheral end of a cut vagus causes a diminution in rate and strength of heart-beat or entire stoppage of the heart in diastole, depending upon the strength of the stimulation. How the action of the vagus on the cardiac muscle is brought about is not known.

Pathological-anatomical changes have been observed in the cardiac muscle (atrophy and degeneration) after section of vagus.

The centre for the cardiac inhibitory nerves lies in the medulla oblongata. Its activity is increased by lack of oxygen and increase of carbon dioxide in the blood, and by increased blood pressure. It can also be stimulated indirectly by stimulation carried to it by centripetal nerves from the cerebral hemispheres.

The extent of its activity depends also upon psychical influences (palpitation of the heart). Reflex cardiac inhibition takes place if, e.g. in a frog, the sensory nerves of the abdomen are stimulated by tapping the abdomen (Goltz's tapping experiment).

Atropin and curare in large doses destroy the action of the vagus upon the heart; muscarin and nicotin stimulate the vagus endings in the heart. The action of muscarin is neutralized by atropin, that of curare by nicotin. Digitalin stimulates both the vagus endings in the heart and the centre in the medulla.

(*b*) *The cardiac accelerating nerves* are the nervi accelerantes which pass from the first thoracic and the cervical ganglia of the sympathetic to the cardiac plexus. Stimulation causes increase in the frequency and force of the heartbeat.

It is supposed that their centre lies in the medulla oblongata, and that this is also tonic. If the vagi are cut, electric stimulation of the medulla causes acceleration of the pulse.

2. **Innervation of the blood vessels.**—The muscles of the vessels (smooth muscles) are most developed in the walls of the arteries, less in the veins. The walls of the capillaries are also supposed to be contractile, but this is independent of the nervous system. The nervous elements for the muscles of the vessels lie partly in the walls of the vessels themselves (ganglionic cells, nerve plexus) and partly enter the walls as vaso-motor nerves. There are nerves which constrict and nerves which dilate the blood vessels.

(*a*) *The vaso-constrictor nerves* have their centre in the medulla oblongata, extending from the upper part of the fourth ventricle to the lower part of the calamus scriptorius, on both sides. From this centre the nerve-fibres proceed down the spinal cord and connect with the nerve-cells of the gray matter; from there the fibres pass through the anterior roots and the rami communicantes into the sympathetic. The sympathetic fibres proceed separately (e.g. splanchnic) or with other peripheral nerves (e.g. trigeminus, sciatic) to the blood vessels. Some vaso-motor fibres go directly to the vessels without passing through the sympathetic (e.g. from the roots of the lower lumbar and of the sacral nerves). The vaso-motor nerves are perhaps not in direct contact with muscle fibres, but pass first into the ganglionic cells of the walls, from which the motor fibres proceed to the muscles.

The vaso-motor centre is tonic. Section of a vaso-motor nerve causes a dilation of the vessels innervated by that nerve.

If the cord is cut, dilation of the vessels supplied by the sectioned vaso-motor nerves results; but eventually the tonus is regained, evidently because the cells in the spinal cord, through which the vaso-motor nerves pass, have assumed the function of the centre. Even after section of a peripheral vaso-motor nerve, the tonus is eventually regained; in this case, the ganglionic cells in the walls of the blood vessels assume the rôle of the centre.

The activity of the vaso-motor centre is influenced:

1. Directly by lack of oxygen and the accumulation of carbon dioxide in the blood; this increases its action. Hence asphyxia stimulates this as it does the cardiac inhibitory centre.

2. By stimuli conducted to it through the nerves.

    (*a*) Psychical processes can increase or diminish its activity (pallor by fear; blushing).

    (*b*) The activity can be influenced reflexively.

We classify the centripetal nerves used in this reflex action into:

(α) Pressor nerves, which produce a strong stimulation of the centre and a constriction of the vessels, hence an increase in blood pressure.

(β) Depressor nerves, i.e. centripetal nerves which reflexively inhibit the action of the centre and thereby cause decreased blood pressure.

Pressor nerves are found, e.g. in the trigeminus, superior and inferior laryngeal. An example of a depressor nerve is the *depressor nerve* going from the heart to the vagus and thence to the medulla; stimulation of this nerve causes a lowering of the blood pressure, and decreases the rate of heart-beat.

(*b*) *The vaso-dilator nerves* produce a widening of the vessels by decreasing the tonus of their muscles.

Examples of vaso-dilator nerves:

1. Through the chorda tympani there pass fibres to the submaxillary salivary glands; the stimulation of this nerve causes dilation of the blood vessels of the gland.

2. Stimulation of the nervi erigentes (fibres passing from the sacral plexus to the hypogastric plexus) causes accumulation of blood in the penis and thus produces erection.

In general the vaso-dilators accompany the constrictor nerves. In these cases the existence of the two kinds of nerves can be demonstrated, as they possess different irritability. The dilators are stimulated by a weak, slowly interrupted electrical current, the constrictors need a stronger and faster interrupted current.

After section, the dilators retain their irritability for a much longer time than the constrictors, before degeneration sets in.

How the dilators diminish the tonus of the muscles is not known.

It is supposed that the centre for the vaso-dilators is situated in the medulla.

The innervation of the blood vessels serves to regulate the distribution of the blood to the different parts of the body. This distribution, in so far as it is not dependent upon pure mechanical conditions, is regulated by the tonus of the muscles of the vessels in such a manner that, normally, each part of the body contains the amount of blood that it needs. The more active a certain part of the body is, the more dilated are its blood vessels and the greater the quantity of blood they contain. Simultaneously with the dilation in an active part, there is a constriction in the resting parts of the body.

When the body is at rest, the vessels in the abdomen and the thorax contain more than one-half of all the blood. During digestion, the quantity of blood in the intestine is larger than during fasting. During work, the blood vessels of the muscles are better filled with blood than during rest, simultaneously the abdominal vessels innervated by the splanchnic are constricted.

In the suprarenal glands a substance is formed which increases the tonus of the muscles of the vessels. It acts directly upon the muscle fibres (see Chapter XI).

Small losses of blood are compensated by general constriction of the vessels. But for great loss of blood, amounting to over one-half of all the blood, this compensation is not sufficient; the blood pressure sinks much, the valves do not close completely and the circulation ceases. Death by loss of blood in such cases does not take place because of lack of any constituent of the blood, e.g. the hæmoglobin, but because the vessels are not sufficiently filled and this entails disturbances in the circulation. If the lost blood is replaced by an indifferent fluid (0.9% NaCl), the circulation is resumed [**transfusion**]. If the loss of blood amounts to more than two-thirds of all the blood, the hæmoglobin present is not sufficient for respiration, and, notwithstanding that the circulation may be repaired, death takes place because of lack of oxygen. In such a case, life can be saved only by the transfusion of human blood. Blood from other animals cannot be used because of globucidal action.

CHAPTER V

RESPIRATORY MOVEMENTS

The object of the respiratory movements is, by alternately increasing and decreasing the thoracic cavity, to suck the air into the alveoli of the lungs, and after gas-exchange with the pulmonary blood, to force it out again.

1. THE CHANGE IN THE FORM OF THE THORACIC CAVITY AND OF THE LUNGS

The respiratory movements consist of the alternate increase (inspiration) and decrease (expiration) of the thoracic cavity in all directions.

1. *The dilation of the thoracic cavity in the perpendicular diameter is produced by the contraction of the diaphragm*, which descends by the flattening of its convexity. In this process the muscular portions play the most important part; the central tendon is of secondary importance. The peripheral parts of the diaphragm, which, in expiration, lie against the thoracic walls, are during inspiration drawn away from the walls. In expiration the intestine forces the diaphragm upward into the thoracic cavity.

2. *The dilation of the thoracic cavity in the horizontal diameter is brought about by the elevation of the ribs.*

Each rib is movably joined to the spinal column at two places:

1. By its head to two vertebræ.
2. By its tubercle to the transverse process of one vertebra.

The axis about which the rib turns passes through its neck, hence passes in almost a horizontal anterior-posterior direction.

The ribs incline forward and downward. By their elevating the degree of this inclination is lessened. By this means the cross-section of the thoracic cavity is increased both in its anterior-posterior and lateral diameter, as the horizontal distance between the anterior ends of the ribs and the spinal column increases and the lateral parts of the ribs move apart. Simultaneously with the ribs, the sternum is raised and moved forward. The elevating of the ribs and sternum is dependent upon the twisting of the cartilage of the ribs. This increases the obtuse angle (facing upward) formed by the cartilages of the ribs.

The elevating of the ribs in quiet breathing is brought about by the external intercostal and the intercartilaginous portion of the internal intercostals.

The fibres of the external intercostals, placed between the ribs, slant forward and downward. As the ribs are raised, the insertion points of any fibre approach each other, hence the contraction of the muscle fibres elevates the ribs.

The intercartilaginous portion of the internal intercostals slants downward and backward between two costal cartilages which slant in the same direction as the muscles. Here also the points of insertion approach each other when the cartilages are raised. But these intercartilaginous muscles are of importance only in the lower costal cartilages.

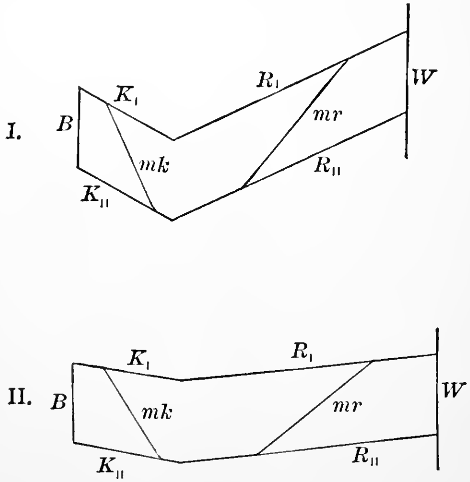


FIG. 2.

In the above scheme (Fig. 2) *W* represents the spinal column; *B*, the sternum; R_I and R_{II} represent two ribs with their external intercostal muscle, *mr*; K_I and K_{II} are two cartilages with their intercartilaginous muscles, *mk*. In I the position in expiration is represented; in II, that in inspiration. It is evident that in II *mr* and *mk* are shorter than in I.

In forced inspiration the following muscles aid in elevating the ribs: scaleni, levatores costarum, serratus posticus superior, sterno-cleido-mastoid; also, after fixation of the arm, as by gripping the table, the pectoralis major and minor and serratus anticus major. During forced inspiration, the levatores alæ nasi contract, causing dilation of the nostrils, and also the crico-arytenoideus postici which cause the dilation of the vocal bands.

The lowering of the ribs during expiration is brought about by the sternum sinking by gravity and by the contraction of the internal intercostal muscles. These muscles cross the externals and therefore act in the opposite direction.

In forced expiration the ribs are lowered by the serratus posticus inferior and latissimus dorsi; further the upward movement of the diaphragm is aided by the muscles of the abdominal walls and the quadratus lumborum, which also aids in the lowering of the ribs.

In the male, the respiration is chiefly effected by the lower parts of the thorax, in the female by the upper.

Normally, the intra-abdominal pressure sinks slightly during inspiration and rises during expiration. Only when the intestines are abnormally filled with food, fæces and gases, does the intra-abdominal pressure rise during inspiration and sink during expiration.

The lungs are two sacs with extensible and elastic walls, placed hermetically in the thoracic cavity, so that their external surface (pleura pulmonalis) is everywhere in close contact with the inner surface of the thoracic wall (pleura costalis), but the two pleura are not grown together. The inner surface of the lungs is much increased by thin membranous projections which form the walls of the alveoli. The internal space of the lungs communicates with the atmosphere by means of air-passages (bronchi, trachea, pharynx, nose). The atmospheric pressure, therefore, presses upon the inner surface of the lung and keeps the external surface of the extensible lung-wall against the thoracic wall.

After expansion of the thorax the atmospheric pressure stretches the lung-sac and enlarges it.

Even in the expiratory position of the thorax, the walls of the lungs are stretched. If, in a dead body, the thoracic wall is opened so that the air can enter the pleural cavity, the lungs withdraw from the thoracic walls. If, previous to opening the thorax, a manometer is connected with the trachea, this will, on opening the thorax, indicate the pressure which the tension of the pulmonary wall exerts. In the pleural cavity, in the expiratory position, there is a corresponding negative pressure of about 3–5 mm Hg. During ordinary inspiration this is increased by about 9 mm; during forced inspiration, by 30–40 mm.

2. THE VARIATION IN PRESSURE OF PULMONARY AIR DURING RESPIRATION; RESPIRATORY CAPACITY

During the inspiratory dilation, the pressure of the air in the lungs sinks, while during expiration it rises. This decrease in pressure causes the external air to rush in; the increase in pressure during expiration forces the air out of the lungs. These respiratory changes in pressure amount, in quiet breathing, to 1–3 mm Hg; in forced respiration they are greater.

The respiratory volume is determined by exhaling into an instrument used for measuring the volume of gases (gasometer, spirometer) or by letting the inhaled or exhaled air pass through a gas-meter.

A part of the inspired air does no service in the gas-exchange, as it does not reach the alveoli but remains in the air-passage (trachea, bronchi, nose). The size of this "dead space" is 100–150 cc.

Tidal air is the air inhaled and exhaled during quiet respiration; in the adult male it is about 500 cc.

Complemental air is the air which can be inhaled, in excess of the tidal air, by forced inspiration; it is about 2500 cc.

Supplemental air is the air which can be expelled, besides the tidal air, by the most forcible expiration; it is about 1500 cc.

These volumes combined form the *vital capacity* (4500 cc), i.e. the greatest possible inhaled and exhaled volume of air.

Residual air is the air which, after the deepest expiration, remains in the lungs and may amount to about 1200 cc.

Because of the radiation of heat and the evaporation of water from the mucous membranes, the inspired air in its passage to the lungs is warmed to the body temperature and saturated with water vapor.

Dust which has been brought to the air-passages by inspiration is forced out by the movement of the cilia of the epithelial cells of mucous membrane.

Respiratory sounds. During breathing the movement of the air produces sounds which may be heard by placing the ear upon the chest-wall. Above the trachea and the bronchi there is heard a blowing noise, like the sound of the German "ch" (bronchial breathing), both during inspiration and expiration. Above the tissue of the lungs we hear a sighing sound (vesicular murmur) which is strong during inspiration, feeble during expiration.

3. FREQUENCY AND RHYTHM OF RESPIRATORY MOVEMENTS. INNERVATION OF THE MUSCLES OF RESPIRATION

Adults breathe about 18 times in one minute, children oftener (during the first year, on the average, 44 times).

Expiration follows immediately upon inspiration. The proportion of the length of the inspiration to that of expiration is about as 10 : 12. Between the end of expiration and the beginning of the next inspiration there is, as a rule no pause.

The motor nerves for the muscles of respiration proceed from the spinal cord at the anterior roots of the cervical and dorsal region. They are the **phrenic nerves** for the diaphragm and the intercostal nerves for the intercostal muscles.

The **respiratory centre** lies in the medulla oblongata, on both sides of the posterior point of the fovea rhomboid.

Destruction of this spot causes immediate death because breathing stops (hence the spot is called the nœud vital).

Some authors suppose that this spot is a nerve trunk which unites the nuclei of the 5, 9, 10 and 11 cranial nerves with the nuclei of the motor respiratory nerves. It has also been advanced that the real respiratory centre lies not in the medulla but in the spinal cord.

The centre is composed of an inspiratory and an expiratory centre which act alternately; it is bilaterally double, but the two parts are connected by commissural fibres so that they are always stimulated simultaneously.

The nerves from the respiratory centre to the motor nuclei of the nerves of respiration run in the two lateral columns of the spinal cord (*respiratory bundle*).

The stimulation of the respiratory centre can be brought about directly and indirectly.

1. *Direct stimulation.*—Normally the respiratory movements take place involuntarily because the respiratory centre is continually and directly stimulated. The normal stimulation is automatic, not reflex for the centre retains its activity after all the centripetal nerves which can stimulate it have been severed.

The normal stimulation is the lack of oxygen and the accumulation of carbon dioxide in the blood. As the arterial blood contains so little oxygen and so much carbon dioxide, the centre is stimulated even by the arterial blood. This brings about the normal quiet breathing which is called **eupnœa.**

If the blood is well aërated by deep respiration, so that it contains much oxygen and little carbon dioxide, the respiratory centre is not stimulated. Hence, breathing is suspended —**apnœa**.

Apnœa is, indeed, partly due to a stimulation, by the expansion of the lungs, of centripetal inhibiting vagus fibres (see below); for, after section of the vagi, it is more difficult to produce apnœa.

The embryo in uterus is in apnœa, the blood of the mother causing a sufficient gas-exchange in the placenta. If the circulation of the umbilical cord (by compression, for example, of the cord) or if gas-exchange in the placenta (by premature rupture of the placenta) is prevented, lack of oxygen and accumulation of carbon dioxide in the blood of the embryo takes place. This can bring about respiratory movements before birth.

If, by lack of aëration, the arterial blood becomes poorer in oxygen and richer in carbon dioxide than the normal blood, respiration is increased, the inspirations becoming deeper and more frequent—**dyspnœa.** Strong continued dyspnœa finally produces death through paralysis of the respiratory centre—suffocation, **asphyxia.**

The normal stimulation of the respiratory centre by lack of oxygen and accumulation of carbon dioxide serves to regulate the intensity of the respiratory movements according to the need of the organism.

In the active muscle there are supposed to be formed other products besides the carbon dioxide which stimulate the respiratory centre.

Many authors suppose that the carbon dioxide does not only stimulate the centre directly but also indirectly, in that it stimulates the endings of the centripetal nerves in the tissue where it is formed, and these in turn reflexly increase the respiration.

Increase of temperature augments the action of the respiratory centre—*heat dyspnœa* (e.g. in fever).

2. *Indirect stimulation* of the respiratory centre is produced by stimulations carried to the centre by nerves.

(*a*) From the cerebral hemispheres, psychical influences can modify the number, depth, and rhythm of inspirations. On the one hand, we can, to a certain extent, voluntarily influence respiration; while, on the other hand, respiration is involuntarily influenced by the emotions (fear, anger, etc.).

(*b*) Reflex modifications of respiration are, e.g., the expulsive expirations which are called sneezing and coughing and are produced by the stimulation of the sensory nerves of the mucous membrane of the nose (trigeminus) and of the larynx (superior laryngeal). Besides these respiration is reflexly influenced by a large number of other sensory stimuli.

The most important reflex influence upon breathing is brought about by the **vagus.** Section of both vagi causes deeper but slower inspiration, so that the total quantity of air expired during a long period of time is not altered. Stimulation of a central end of a cut vagus produces no typical alteration in respiration. Sometimes the effect is predominantly inspiratory, sometimes expiratory. If the lungs of an animal are artificially inflated, an expiratory movement is produced; by artificial expiration (sucking the air out of the lung) an inspiratory movement is called forth. It is therefore supposed that the vagus supplies the lungs with two kinds of sensory fibres, of which the one stimulates expiration, the other inspiration (inspiratory inhibiting and expiratory inhibiting). Of these the first is stimulated by inflation of the lung during inspiration, the second by the collapse of the lung during expiration. By means of this mechanism the inspirations are decreased or increased.

This action of the vagus seems to have for its object to prevent the overfatigue of the muscles of respiration, for by shallow breathing the muscles are less exerted.

CHAPTER VI

LYMPH, LYMPH GLANDS, SPLEEN

1. THE LYMPH

FROM the blood capillaries there continually transudes to the tissues a fluid, which, as *tissue fluid*, surrounds the cells and carries to them their nourishment. After the giving off of these substances and the taking up of the end-products of metabolism, the tissue fluid goes as lymph from the minute tissue spaces to the lymph vessels, then, proceeding through the great lymph trunk (thoracic duct, right lymphatic duct) empties into the blood vessels. A part of the tissue fluid also passes directly through the capillary walls again into the blood.

The lymph is a clear, salty fluid, having a specific gravity of 1.007–1.043 which coagulates spontaneously after being shed. It contains, as the cellular element, lymph corpuscles identical with the leucocytes of the blood, and the plasma of the lymph contains the same substances as the plasma of the blood. These substances are about in the same proportions as in the blood plasma except the proteid substances, the percentage of which is somewhat smaller in the lymph than in the blood. The lymph found in the lymph vessels of the intestine during digestion contains the absorbed fat in the form of a fine emulsion and therefore has a milky appearance; it is called **chyle.**

In man, the quantity of lymph flowing from the thoracic duct is estimated at 1 to 2 litre per day.

Lymph formation.—In the transudation of the lymph from the blood capillaries, physical processes—filtration and diffusion through the walls of the vessels—play a part. It is still a question whether the physical processes alone cause the lymph formation, or whether, besides them, a special activity of the capillary endothelium aids in this formation, whereby the lymph is secreted into the tissues (just as the gland epithelium secretes the gland secretion).

The movement of lymph.—The movement of the lymph is maintained by the force which the ever following lymph forming in the tissues exerts upon that previously formed. The movement is aided by the compression of lymph vessels by the skeletal muscles. The backward movement of the lymph is prevented by the valves. Aspiration, by means of the negative pressure in the thorax, also aids the movement of the lymph.

Many animals are provided with lymph hearts which aid in the circulation of the lymph.

The *serous cavities* (pleural, pericardial and peritoneal cavities) may be regarded as very large lymph spaces; they generally contain small quantities of serous fluid, corresponding to the lymph in composition. Soluble substances injected into these serous cavities are absorbed from the cavities partly by the blood capillaries, partly by the lymph vessels. Concerning the force which causes this absorption, the opinions of authors differ. But it is certain that this absorption is aided by respiration. By means of the alternate dilation and constriction of the lymph spaces of the diaphragm and pleura, the lymph is now sucked from the serous cavities into the lymph spaces and now forced from the lymph spaces into the lymph vessels. Also finely divided solid substances (e.g. fat, pigments) can be absorbed from the serous cavities by the lymph vessels.

2. THE LYMPH GLANDS

These are composed of reticular connective tissue in whose meshes are found groups of cells. Here the leucocytes originate and are passed into the lymph which enters the meshes by the afferent vessel and leaves by the efferent vessel.

The lymph glands also filter the lymph and retain worn-out lymph cells, also injurious substances, e.g. Bacteria, which enter the gland with the lymph. This prevents these substances from entering the general circulation.

The retiform tissue through which lymph passes and which serves for the formation of leucocytes is also found in certain other bodies, e.g. in many parts of the mucous membrane (solitary glands, *Peyer's patches* of the intestine).

The **thymus gland** has the same structure and function as the lymph glands. It is well developed in the embryo and child, but begins to degenerate at the tenth year and finally disappears entirely.

3. THE SPLEEN

The spleen consists of a framework which is made of a trabecular tissue and supports the spleen-pulp, a reticular tissue with many cellular elements. In many places the cells are clustered, forming the spleen follicles. Some of the cells of the pulp are leucocytes, some are large multinuclear cells, some are red blood corpuscles and some are cells which have ingested red blood corpuscles. According to most authorities, the blood is supposed to flow from the capillaries into the meshes of the pulp and from there through the splenic vein.

In the capsule of the spleen there are smooth muscle fibres which by their contraction regulate the size of the spleen.

Leucocytes are formed in the spleen and thrown into the blood, for the blood in the splenic vein contains more leucocytes than the arterial blood. This function corresponds to the anatomical structure of the spleen, which is very much similar to that of lymph glands. But white blood corpuscles are not only formed in the spleen as in the lymph glands, but they are also destroyed there. This is supported by the fact that we find in the spleen considerable quantities of substances which have been derived from the nuclei of the destroyed white blood corpuscles. They are the xanthin bases, decomposition products of nuclein, which must be regarded as the precursors of uric acid. If the spleen-pulp is heated with blood, uric acid is formed. As it is supposed that, in mammals, uric acid is formed from the nucleins of the nuclei, the spleen must be the chief place of uric acid formation.

The fact that we find, in the spleen-pulp, cells which contain red blood corpuscles, in all stages of decay, favors the view that the red blood corpuscles are also destroyed in the spleen. Red blood corpuscles are supposed to be formed in the embryonic spleen.

The spleen can be extirpated without injury to the body; its functions can be entirely taken up by other organs (lymph glands, red bone marrow, liver).

In many cases of infectious diseases, the spleen is much enlarged. Some claim that the spleen produces cells [phagocytes ?] which neutralize the cause of the disease.

CHAPTER VII

SECRETIONS

1. SECRETIONS IN GENERAL

SECRETIONS are of various significance for the animal economy. Some serve to remove from the body the waste products of metabolism (e.g. secretion of urine); some furnish the fluids necessary for the digestion and absorption of foods; again, there are the secretions of milk-glands, the food for the infant; the secretion of the sebaceous glands, a protective covering for the skin; and the sweat secretions which regulate the temperature of the organism.

Secretions are produced by the **gland-cells,** i.e. by modified epithelial cells. They are found:

(*a*) As isolated cells between other epithelial cells.

In this group belong the secreting epithelial cells of the mucous membrane (globlet cells), cylindrical cells which, when empty of secretion, contain granular protoplasm and oval nuclei; this granular protoplasm during the formation of secretions changes to a clear mass, the unchanged protoplasm and the nuclei withdrawing to the bottom of the cell. The clear mass then leaves the cell, is deposited on the free surface and constitutes the secretion. In the globlet cells the formation and the pouring out of the secretion take place simultaneously; finally the whole cell empties itself and dies.

(*b*) As congregated in the glands.

The **glands** are invaginations of the skin or mucous membrane of various forms, some in the form of tubes (tubular), some in the form of sacs (acinous), branched or unbranched.

The wall of the gland duct forms a layer of cells which is supported by a membrana propria and surrounded by capillaries. The glands also contain lymph vessels, muscles and nerves.

The secreting cells are generally only found at the closed end of the gland duct, while the other part serves as an excretory duct for the secretion.

The **process of secretion** is not merely a filtration of the fluids of the blood through the walls of the gland, but is brought about by a special activity of the secreting gland-cell, as the following shows:

1. Most of the secretions contain substances not found as such in the blood, which must therefore have been made by chemical processes in the gland-cells (e.g. the ferments of digestive fluids, the caseinogen and the lactose of milk, etc.).
2. Secretion, in many cases, does not occur continually but only at stated times, while blood pressure should cause a continual filtration.
3. The pressure of the secretion in the duct of the gland may be higher than that of the blood. Furthermore, secretion can take place in glands free from blood and even in excised glands.
4. In many cases the secretion is accompanied by morphological changes in the cells of the gland.
5. Many secretions are under the influence of specific secretory nerves. The nerve-fibres in the salivary glands end in the gland-cells.

2. SALIVARY SECRETION

1. *Composition of saliva.*—The saliva of the mouth is a secretion of all the glands of the mouth-cavity. It is a colorless, cloudy, stringy fluid, having a weak alkaline reaction. The amount secreted in twenty-four hours is estimated at from one to two litres.

The cloudiness of the saliva is due to the mucin, salivary corpuscles and discarded epithelial cells of the mouth-cavity. The salivary corpuscles are recently loosened gland-cells or migrated leucocytes.

The saliva contains 99–99.5% water, 0.1–0.2% salts (including potassium sulphocyanate), 0.1–0.4% organic material including proteids, mucin and a diastatic ferment, *ptyalin*, and last of all, gases, especially carbon dioxide.

2. *Morphological phenomena accompanying salivary secretion.*—The buccal cavity contains two kinds of glands:

(*a*) **Albuminous** or serous glands furnish a secretion free of mucin. To this class belong the parotid and, in many animals (rabbits), the submaxillary also, and a part of the glands of the mucous layer of the mouth-cavity.

The cells of the albuminous glands have, during rest, a small amount of clear, finely granular protoplasm and a small irregular nucleus. In the active condition the cells are smaller, the amount of the granular substance is increased, and the nuclei become more nearly spherical.

(*b*) The **mucous glands** furnish a secretion containing mucin; this group contains all the glands except the albuminous glands.

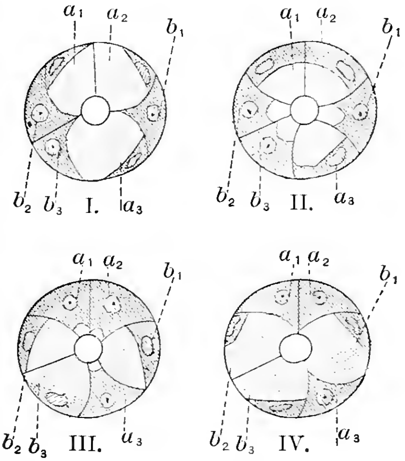


FIG. 3.—REPRESENTING THE ORIGIN OF DEMILUNES. (After Stöhr.)

Many glands, e.g. the sub-maxillary glands of man, contain both albuminous and mucous gland-cells.

In the mucous glands we find two kinds of cells:

1. The demilune of Giannuzi (also called border cells)

lying at the periphery of the gland wall. They are flattened cells with protoplasm rich in granules.

2. Muciparous cells, reaching to the lumen of the gland duct; their protoplasm is but slightly granular, more hyaline.

These two forms of cells are of the same kind, but are in different conditions of secretion. The well-filled muciparous cells, a_1, a_2, a_3 (Fig. 3, I) crowd the empty border cells b_1, b_2, b_3, away from the lumen. After discharging their secretion, the hitherto muciparous cells are crowded away by the now filled border cells and are themselves changed to border cells (compare the change in the form of the cells in the successive stages II, III, IV of Fig. 3).

3. *Influence of the nervous system upon secretion.*—The salivary secretion is stimulated reflexly when food, especially dry food, stimulates the nerves of the mucous membrane of the mouth. Salivary secretion is, therefore, dependent upon the nervous system.

The *submaxillary* and *sublingual* glands are supplied with the following secretory nerves:

(*a*) Fibres from the *facial* nerve which, passing through the *chorda tympani*, approach the glands along with the lingual. Stimulation of these fibres produces a rich flow of thin secretion.

(*b*) Fibres from the *cervical sympathetic;* the stimulation of these yields a scanty flow of thick saliva.

The chorda fibres also contain the vaso-dilators; the sympathetic contain the vaso-constrictors for the blood vessels of the glands.

The *parotid* glands are supplied with the following secretory fibres:

(*a*) Fibres from the *glossopharyngeal* passing through the nervus Jacobsonii, Petrosus superficialis minor to the oticum ganglion, from there through the *auriculo temporalis* to the gland. Stimulation of these produces a great flow of thin saliva.

(*b*) Fibres of the *cervical sympathetic*, stimulation of which yields a scanty flow of thick secretion.

The centre of the secretory nerves is situated in the medulla oblongata.

For some time after the section of the secretory nerves the gland secretes continuously (paralytic secretion) till it finally dies and degenerates. The cause of this paralytic secretion is still in the dark.

The pressure of the secretion is measured by placing a canula in the duct of the gland and connecting this with a manometer. In the submaxillary of the dog the pressure during chorda stimulation may be above 200 mm Hg, this being 100 mm more than the blood pressure in the blood vessels of the gland.

The secretion of the salivary glands is said to be warmer than that of the blood carried to the gland. Hence heat is produced during salivary secretion.

The active gland shows certain electrical phenomena, the meaning of which is not yet understood.

*

Upon nervous stimulation, secretion can go on in a bled animal, in which case the gland is no longer supplied with blood.

3. GASTRIC SECRETION

1. *Composition of gastric juice.*—Gastric juice, the secretion of the gastric glands, is a clear, transparent or slightly yellowish fluid, having an acid reaction and a specific gravity of 1.003–1.006. It contains 0.29–0.60% solids which include 0.10–0.17% ash.

Its characteristic constituents are:

(*a*) Free **hydrochloric acid,** in man 0.2%; in dogs a little more.

The gastric juice gives the following tests for free hydrochloric acid: To gastric juice add Günzburg's reagent (2 g phloroglucin, 1 g. vanillin in 30 g absolute alcohol) and evaporate. This gives a red color. Gastric juice imparts a blue color to methyl-violet and congo-red.

(*b*) **Pepsin,** a ferment which in an acid solution digests proteids and gelatin. According to its composition, it is a proteid-like body. The antecedent of pepsin in the gastric glands is the pepsinogen, a substance which can be extracted from the gastric glands by a soda solution, and can be changed to pepsin by hydrochloric acid.

(*c*) **Rennin,** a coagulating ferment, of unknown composition. It causes the casein coagulation of milk. Its antecedent is rennet-zymogen, which can be extracted from the gastric mucosa by water and can be changed to rennin by the addition of acid.

The fasting stomach contains no gastric juice; its mucous membrane is covered with mucus.

2. *Morphological phenomena accompanying the secretion.*—The tubular glands of the mucosa may be classified as:

(*a*) Glands composed of only one kind of gland-cell. They are found in the pyloric end only and are therefore called **pyloric glands.**

(*b*) Glands composed of two kinds of cells; these are found in the fundus —**fundic glands.**

The pyloric glands contain cylindrical cells which, in a single layer, form the duct. The fundic glands contain, besides the cylindrical cells (the so-called **chief** or central cells), also a second kind called the **ovoid** or **oxyntic** cells. These ovoid cells lie isolated between the chief cells and the membrana propria and do not form a continuous layer. The ovoid cells are surrounded by secretory capillary loops in a basket-like form, which are connected with the lumen of the gland.

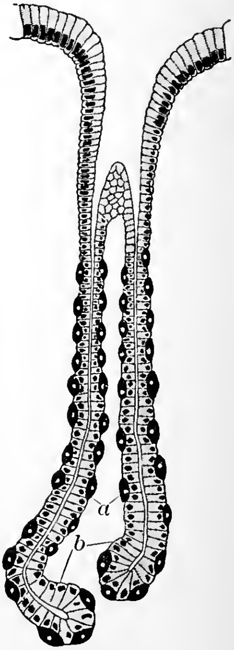


FIG. 4.—FUNDIC GLANDS. (After Heidenhain.) The protoplasm of the chief cells is clear, that of the ovoid cells is darker and granular. Arrangement of the ovoid (*a*) and chief cells (*b*) of the fundic glands.

Both the fundic and pyloric glands form pepsin and rennin, hence the cylindrical cells (chief cells of the fundic glands) must be regarded as secreting pepsin and rennin.

The isolated pyloric end of the stomach secretes a gastric juice which is not acid. As the ovoid cells are lacking in this part, it is supposed that the hydrochloric acid is secreted by these cells.

The morphological changes during the activity of the cells are as follows: The chief cells, which are large and granular during fasting, at first become still larger, but from the sixth to the ninth hour of digestion they become smaller and clearer. The ovoid cells, small during fasting, are much enlarged during digestion.

Concerning the origin of the characteristic constituents of gastric juice, nothing is known for certain. Both ferments must, however, be regarded as a product of the gland-cells.

As to the formation of the hydrochloric acid it is difficult to understand how a free strong acid can originate while the blood and the secretory cells have an alkaline reaction. An explanation has been sought in the mass action of weak acids (e.g. carbonic acid) upon the chlorides of the blood. In the same way as hydrochloric acid is set free by the mass action of the carbonic acid of the blood upon sodium chloride and is then taken up by the blood corpuscles (see page 59), the mass action of carbonic acid in the ovoid cells might set free the hydrochloric acid.

Recently it has been supposed that the acid is not formed in the gland-cells, but is formed from the chlorides of the food in the following manner:

By dissolving in water a part of the sodium chloride of food is split up into sodium and chlorine ions. The free sodium ions in the stomach are supposed to pass through the walls of the stomach by diffusion in exchange for the free hydrogen ions of the blood. The walls of the stomach are impermeable to the chlorine ions, hence they remain in the stomach and form, with the hydrogen ions coming from the blood, the hydrochloric acid. This view is based upon the following facts: (1) The cells remain alkaline notwithstanding the acid formation; (2) If chlorides are not present in the stomach, no free acid is supposed to be formed; (3) The alkalinity of the blood and of the urine is increased after the eating of sodium chloride.

3. *Influence of the nervous system on secretion.*

Observations on the secretion of gastric juice can be easily made on men and animals by means of a gastric fistula.

Gastric secretion begins when food has been swallowed, even when food passes out by an esophageal fistula so that it does not reach the stomach. This secretion stops after the cutting of the vagi.

The secretion is dependent upon psychical conditions, as it can be brought about by the mere sight of food. After section of the vagi, secretion still occurs when food is placed in the stomach itself. Whether this secretion is a reflex process in which the vagus does not participate, or whether it is due to direct stimulation of the glands, is not known.

The secretion of the gastric juice is, therefore, called forth by the sight and deglutition of food and is then continued by the presence of the food in the stomach.

4. PANCREATIC SECRETION

1. *Composition of pancreatic juice.*—The pancreatic juice from a newly placed fistula in the pancreatic duct is a clear, thick fluid having a specific gravity of 1.03. Because of its sodium carbonate (0.2%) it has a strong alkaline reaction. Sometimes it coagulates spontaneously. From a permanent fistula the secretion is not so thick (sp. gr. 1.01).

The pancreatic juice obtained by a temporary fistula contains about 90% water, that by a permanent fistula 98%. The solids contain from 0.6–0.9% ash, also organic substances, especially proteids (from a temporary fistula about 10%). The secretion from a temporary fistula is frequently so rich in proteids that, on heating, it coagulates to a solid mass. Pancreatic juice also contains leucin, fat, soaps in small quantities, and the following three characteristic ferments:

(*a*) A diastatic ferment, which acts upon starch like the ptyalin of saliva.

(*b*) Trypsin, a ferment splitting proteids up into proteoses. Trypsinogen, the antecedent of trypsin, is changed to trypsin during secretion and also by the action of oxygen or organic acids.

(*c*) Steapsin, a fat-splitting ferment, which splits the neutral fats into glycerin and fatty acids.

2. *Morphological phenomena accompanying the secretion.*—The cells of the pancreatic glands have a striated outer and granular inner zone. During activity the striated outer zone is widened, the granular inner zone decreases, while during rest the opposite take place (see Fig. 5). In the active condition the cells are separated by sharper (frequently double) boundary lines than during rest.

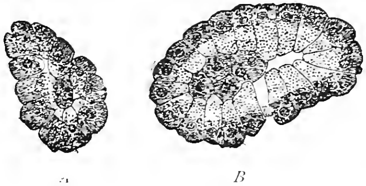


FIG. 5.—GLAND-CELLS OF PANCREAS IN DIFEERENT STAGES OF SECRETION. (After Heidenhain.)

A, first stage of digestion (6–10 hours); the striated outer zone is much broader than the granular inner zone. *B*, second stage of digestion (10–20 hours); the striated outer zone is narrower and the inner granular zone is wider.

3. *Influence of the nervous system upon secretion.*—Secretory nerves for the pancreas are supposed to be present in the vagus and in the sympathetic.

It has been stated that the pancreas of herbivorous animals secretes continuously, while that of carnivorous animals secretes periodically, i.e. only after the introduction of food in the stomach.

Among the substances in the stomach which can reflexly cause pancreatic secretion are chiefly acids, fats, and spices.

Concerning the effects of extirpation of the pancreas see Chapter XI.

5. BILE SECRETION

1. *Composition of bile.*—Bile, the secretion of the liver, is a reddish-yellow or green ropy substance, having an intensely bitter taste. When it is poured from the liver it contains about 1.5–3% solids. During fasting the bile does not flow directly into the intestine, but first into the gall-bladder, where it is concentrated by the absorption of water and the addition of mucus, so that it contains about 16–17%

solids. The amount secreted per diem in the adult is about 1 litre.

Characteristic constituents of bile:

(*a*) *Sodium glycocholate* and *sodium taurocholate* (about one-third of all the solids of bile). In man the sodium glycocholate predominates, in the dog, sodium taurocholate.

To isolate the salts of the bile acids, proceed as follows: Mix bile with animal charcoal, evaporate, extract the residue with alcohol, add excess of ether; this precipitates the salts of bile acids in delicate needle crystals (crystallized bile). Concerning the characteristics of the bile acids see page 49.

(*b*) *Bile pigments*, bilirubin, biliverdin, and sometimes also hydro-bilirubin; see page 50.

Besides these, bile contains mucin, cholesterin, lecithin, fat and fatty acids, salts (chiefly sodium carbonate and phosphate), and a little iron.

In the gall-bladder the solid constituents of the bile may be precipitated as gallstones. These may be composed of a compound of calcium with bilirubin or of cholesterin.

2. *Chemistry of the liver.*—The liver is the largest gland in our body. It weighs about 1.5 kg and contains about 30% solids, chiefly proteids (20%), some fats, extractives, and a varying amount of carbohydrate in the form of glycogen and grape-sugar. Its ash forms about 1% of its weight and is characterized by its high per cent of iron.

The iron in the liver is partly in inorganic, partly in organic combination. The iron held in organic union is found in two nucleo-proteids, hepatin and ferratin. In the hepatin the iron is held very closely, but ferratin has more the character of an iron albuminate since its iron can be split off by hydrochloric acid.

The iron of the liver, like the bile pigments, is derived from the hæmoglobin of the red blood corpuscles which are destroyed in the liver. The iron is excreted chiefly by the walls of the intestine, and in smaller quantities by the bile and urine.

3. *Structure of the liver.*—The gland-cells of the liver are irregular polygonal cells having granular protoplasm and one or more nuclei. The protoplasm contains pigment

granules and fat droplets and, in well-fed animals, masses of glycogen. In the fasting condition the cells are small, cloudy, and have not well-defined contours; during digestion they are larger, the centre being clear and the periphery containing large granules.

When a liver is cut through, the liver lobules (Fig. 6) can be seen. These are composed of cells arranged in rows, radiating from a vein (the vena centralis) in the centre of the lobules to the circumference. But these rows of cells are not isolated, for each cell is connected with those above and below it.

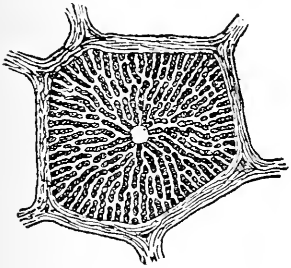


FIG. 6.—CROSS-SECTION OF A LIVER LOBULE OF A PIG. RADIAL ARRANGEMENT OF THE LIVER CELLS.
(After Heidenhain.)

Between the cells are found both the small bile ducts (the so-called bile capillaries) and the blood capillaries.

The *bile capillaries* stand in the same relation to the liver cells as the lumen of other cells to the gland-cells. Two cells form the wall of the bile capillary, the latter being formed by two groove-like depressions in the surfaces of two neighboring cells which are fitted together. Each liver cell comes in contact with bile capillaries on more than one side. The bile capillaries empty into the bile ducts coursing between the lobules.

The *blood capillaries* originate from the intralobular branch of the portal vein, they traverse the lobules radially and finally join the central vein of the lobule which connects with the intralobular branch of the hepatic vein. The blood capillaries also run between the liver cells, but in such a manner that the blood and bile capillaries never touch each other but are surrounded on all sides by liver cells. *Hence, a liver cell or a part of a liver cell is always placed between a blood and a bile capillary.*

The branches of the *hepatic artery* run only in the intralobular tissue; their capillaries empty in veins which end in the portal vein. The lymph vessels accompany the portal vein.

4. *The formation of bile.*

The secretion of bile can be investigated by means of the biliary fistula.

The secretion of bile is continuous, but is increased 3–5 hours after the taking of food. This increase of secretion during digestion seems to be brought about by absorbed substances which stimulate the liver directly. As such, the bile elements (bile acids) absorbed from the intestine are especially active.

The pressure in the bile ducts may be higher than that in the portal vein, yet the secretion of bile is dependent upon blood pressure. If the blood pressure decrease, less bile is secreted and the bile contains more solids. Ligaturing the portal vein, stimulation of the spinal cord and of the splanchnic nerve (because of diminished amount of blood carried to the liver, due to the constriction of the arteries), cause inhibition of bile secretion.

Secretory nerves for the liver have not yet been demonstrated.

5. *The discharge of bile.*

The bile is driven out of the liver by the pressure of the newly made bile. The ductus choledochus has at its opening into the intestine a sphincter which regulates the flow of the bile. The muscles of the gall-bladder and ductus choledochus also aid in discharging the bile. The nerves for these muscles are supposed to be the vagus and splanchnic.

If the flow of bile is prevented, the bile enters the lymph vessels and thence passes into the blood (jaundice). The bile is then excreted by the kidneys.

6. SECRETION OF INTESTINAL JUICE

To investigate the secretion of the intestinal glands, an intestinal fistula must be made. A piece of the intestine is isolated but its connection with the mesentery is not severed. Either both ends of this piece of intestine are sewn into the incision of the abdominal wall, or only one end is thus fixed while the other is closed by a ligature. The two ends of the main intestine are sewn together.

1. *Composition of intestinal juice.*—The juice of the small intestine is a colorless, alkaline fluid having a specific gravity of 1.007. It contains besides salts, some proteids, a diastatic and an inverting ferment, and, according to some authors, a proteolytic ferment.

The large intestine furnishes a mucous secretion without ferments.

2. *The secretion.*—The intestinal juice is the secretion of

the glands of Brunner in the duodenum and of the crypts of Lieberkühn in the whole intestine. Concerning the secretion of Brunner's glands and the conditions of their secretion nothing is known.

The crypts of Lieberkühn of the small intestine are simple tubular glands, placed in thick clusters between the villi of the mucous membrane. They secrete the intestinal juice containing the diastatic ferment. The secretion takes place when the mucous membrane of the intestine is directly or reflexly stimulated by the taking up of food. As the secretion also takes place in those parts of the intestine not directly stimulated, it is dependent upon the nervous system. The secretory nerves are, however, not known.

The muciparous glands of the large intestine contain many globlet cells forming mucus; these globlet cells are only found occasionally in the glands of the small intestine.

The intestinal glands also seem to regenerate the epithelial glands of the villi. In the intestinal glands new cells are continually formed by mitotic division; these new cells pass upward to take the place of the broken-down epithelial cells of the free surface of the mucous membrane.

7. RENAL SECRETION

1. *Composition of urine.*—Urine, the secretion of the kidneys, is, in man, a yellow or reddish-brown fluid having a specific gravity of 1.017–1.040. Its reaction is generally acid (due to acid sodium phosphate), but after a meal of vegetables containing the salts of vegetable acids, which in the body form carbonates, it may be neutral or alkaline. Its reaction is alkaline also during the period of greatest gastric digestion because the alkalinity of the blood is increased on account of the acid formation in the stomach, and this excess of alkali is excreted in the urine.

When urine stands for a certain length of time, putrefaction sets in by which the urea is changed to ammonium carbonate (alkaline urea fermentation); this causes the urine to become alkaline. Such alkaline urine is cloudy because of a precipitate of ammoniomagnesium phosphate, ammonium urate, and the phosphates and carbonates of the alkali earths.

The amount of urine excreted per day is generally about 1.5 litres.

Urine contains about 4% solids, among which are:

(*a*) Nitrogenous wastes of metabolism: urea 2.3% (35 g. per day), uric acid (0.05% in the form of acid salts of the alkalies), hippuric acid, kreatinin (0.05%), xanthin, hypoxanthin, ammonia salts (0.04%). The urea contains 83–86% of all the nitrogen of the urine.

To obtain the urea from urine, evaporate the urine to small bulk and add nitric acid; this throws down crystals of nitrate of urea.

The uric acid crystallizes from the urine when that is mixed with one-tenth its volume of concentrated hydrochloric acid and left standing in the cold. This separation of the uric acid takes place in concentrated and strongly acid urine without the addition of hydrochloric acid (sedimentum lateritium, see page 46).

The urea contains 83–86% of all the nitrogen of the urine; ammonia contains 3–4%; the remaining nitrogen is distributed among uric acid, kreatinin, etc.

(*b*) Salts about 1.5%, chiefly sodium chloride (a little more than 1%) and, in smaller quantities, phosphates, sulphates, and traces of oxalates; among the bases are sodium, potassium, magnesium, calcium, and traces of iron.

Besides the sulphates, the urine contains sulphuric acid combined with the ethereal sulphates of the benzene derivatives, e.g.:

Phenyl-sulphuric acid	$C_6H_5.O.SO_2.OH$
Kresyl-sulphuric acid	$C_7H_7.O.SO_2.OH$
Indoxyl-sulphuric acid or indican	$C_8H_6N.O\ SO_2.OH$
Skatoxyl-sulphuric acid	$C_9H_8N.O.SO_2.OH$

To demonstrate the presence of indican, add a like quantity of concentrated hydrochloric acid and a little calcium chloride solution to the urine. Indigo is produced which may be collected by shaking it with chloroform.

The benzene derivatives, with which the sulphuric acid unites, are derived from the intestine, where they are formed by proteid putrefaction: phenol, indol, skatol; the last two, after being absorbed, are oxidized to indoxyl and skatoxyl. From this decomposition of the proteid in the intestine arise aromatic oxyacids (oxyphenyl-acetic acid and oxyphenyl-propionic acid), which are absorbed from the intestine and excreted by the kidneys.

(*c*) In small quantities there are present in the urine urinary pigments, among which is sometimes found urobilin, which is supposed to be identical with hydro-bilirubin.

Finally there are present in urine, gases, chiefly carbon dioxide, traces of nitrogen and oxygen.

In certain diseases, e.g. diabetes, the urine contains grape-sugar, aceton, oxybutyric acid and diacetic acid; in inflammation of kidneys it contains proteids; in icterus, bile pigments and acids; and in hæmaturia, blood pigments.

2. *The structure of the kidneys.*

The kidneys are composed of a uniformly darkly stained cortex and a radially striated medulla consisting of a large number of Malpighian pyramids.

In the cortex the uriniferous tubules of the gland are coiled (convoluted tubules); in the medulla they are straight (tubuli recti). Each uriniferous tubule begins in the cortex (*R*, Fig. 7) as a spherical dilation, the Malpighian body (*g*), from which proceeds the convoluted tubule (*f*). This proceeds downward into the medulla, *M*, as a straight tubule (*e*), then turns and forms the loop of Henle. The ascending limb of Henle's loop joins the intercalated part (*c*), which, turning downward towards the pelvis, forms a straight collecting tubule (*b*). The collecting tubules join to form a duct (*a*), which at the apex of the pyramids empties into the pelvis of the kidneys.

The Malpighian bodies are composed of a knot of blood vessels, the glomerulus (*g*), which is placed in the blind, sac-like ending of the uniferous tubule (the Bowman capsule) so that it is almost entirely surrounded by the capsule. The fold of the capsule bordering on the glomerulus is composed, in young individuals, of cuboidal cells, while in older persons the cells are flattened. The outer fold of the capsule is made up of flat polygonal cells. It is continued downward, forming the walls of the convoluted tubule whose cells are radially striated and have granular protoplasm. The cells in the walls of Henle's loop, of the intercalated portion, and of the collective tubules are cylindrical epithelial cells.

The uriniferous tubules are surrounded by connective tissue, in which are found the blood vessels.

The branches of the renal artery proceed from the hilus to the boundary between the cortex and medulla (*a*, Fig. 8). Here they give off branches which radiate outward (*b*) and send branches to each of the glomeruli (*c*). After giving off these branches, the arterial trunk ends in capillaries in the outer part of the cortex (*d*).

Each glomerulus is formed by the afferent vessel (vas afferens)

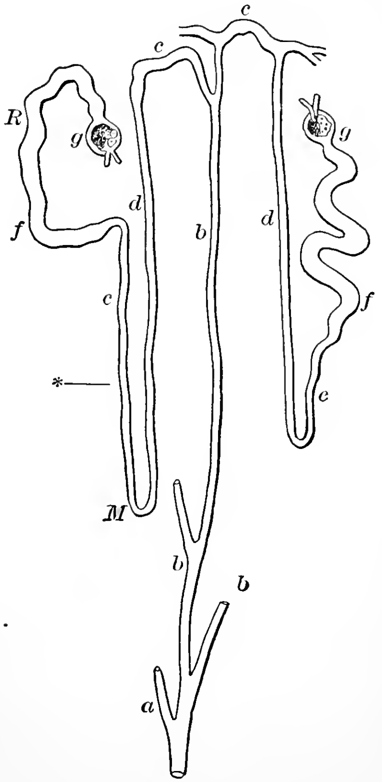


FIG. 7.—DIAGRAM OF A URINARY TUBULE.

dividing into a great number of loops. These loops then join each other again, forming the vas efferens (*i*) which passes out of the glomerulus and then splits up into capillaries. The capillary net in the cortex surrounds the convoluted tubules (*g*).

The arteriolæ rectæ (*k*) in the medullary portion are derived partly from the vasa afferentia of the deepest glomeruli, partly from the renal artery directly. These form straight capillaries in the medulla, and at the papillæ (*m*) form a ring-like capillary network. The capillaries in the cortex empty into the veins radiating from the pelvis to the circumference (*h*); into these the smallest veins of the medulla also empty (*l*).

3. *Conditions of renal secretion.*

(*a*) The quantity of urine secreted depends upon the blood pressure in the renal artery; it decreases when, e.g. by bleeding, the blood pressure decreases; it increases when, e.g. by ligaturing of other blood vessels, the pressure in the renal arteries is increased.

Partial closure of the renal vein (venous statis) decreases renal secretion, which appears to be due to the compression of the urinary tubules by the strongly dilated capillaries and smaller veins.

(*b*) The renal secretion ceases for a long time when the supply of blood to the kidneys has been cut off by compression of the renal artery for but a few minutes.

(*c*) There are certain substances which, taken into the body, increase renal secretion, e.g. water, urea, sodium chloride, sodium nitrate, caffein, grape-sugar. The action of these diuretics still takes place when the renal secretion has been entirely stopped by a too low blood pressure. On the other hand, there are substances, e.g. atropin, which inhibit renal secretion.

(*d*) Concerning the effect of the nervous system upon renal secretion—leaving out of consideration the indirect influence of the vaso-motor nerves—nothing is yet known.

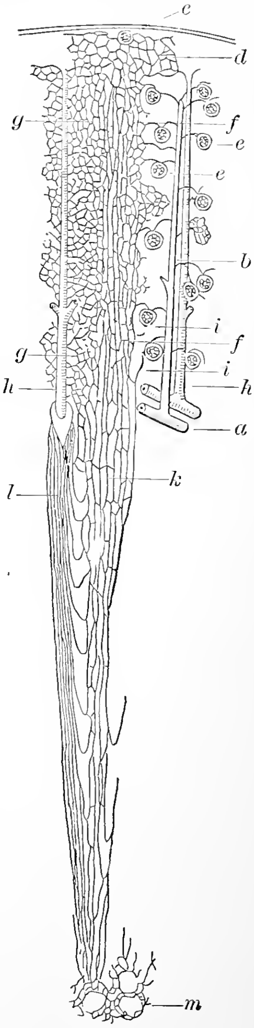


Fig. 8. — Scheme of the Blood Vessels of Kidneys.

Notwithstanding the fact that renal secretion depends upon blood pressure, we cannot regard it as a mere process of filtration of the blood fluid through the walls of the urinary tubules. This assertion is based upon the following facts:

1. The composition of the urine differs quantitatively from that of proteid-free blood plasma. Many substances (e.g. urea) are much more abundant in the urine than in blood.
2. The harmful effect of ligaturing the renal artery cannot be explained on the theory of mere filtration.

Renal secretion is, therefore, dependent upon the special activity of the gland-cells. These cells are temporarily paralyzed by the stoppage of circulation (compression of renal artery), so that they are not able to secrete. Diuretics, in so far as they do not affect blood pressure, stimulate the cells toward greater activity.

According to the theory accepted at present, renal secretion takes place as follows: The cells of the Bowman capsule secrete chiefly water, while the cells of the convoluted tubules secrete the solid constituents of urine, and this secretion is concentrated as it passes through the urinary tubule by the absorption of water from it.

This view is based on the fact that sodium-sulphindigotate, injected into the blood, is excreted by the kidneys, and is found, during its excretion, only in the inner part of the cells of the convoluted tubules and lower down in the lumen of the urinary tubules, while it is never found in the cells of the capsule.

Most of the substances excreted in the urine are not formed in the kidneys but in other organs, and are carried by the blood to the kidneys to be picked out by them. Some substances can also be made in the parenchyma of the kidneys, e.g. the hippuric acid. That energetic oxidations take place in the kidneys is proven by the facts that the blood in the renal veins is venous, and that the secreted urine is often warmer than the blood flowing to the kidneys.

Beside the end-products of metabolism, there are also excreted substances which are indeed normal constituents of the body but which, for some reason, have accumulated in the blood in too large quantities (e.g. many salts, grape-sugar in case of glycosuria), also substances normally not found in the body (e.g. drugs, such as potassium iodide, salicylic acid, santonin, etc.).

4. *Micturition.*—The urine is driven from the urinary tubules into the pelvis by the pressure of the secretion. From the pelvis the urine is forced by the peristaltic contractions of the two ureters into the bladder. The bladder is closed by the tonic contraction of the sphincter vesicæ. During micturition, the tonus of the sphincter is inhibited and the contraction of the detrusor urinæ diminishes the compass of the bladder. The muscles of the bladder are supplied with nerves from the sacral and lumbar nerves and from the sympathetic. Their centre lies in the lumbar cord.

8. THE SECRETION OF SWEAT

1. *Composition of sweat.*—Sweat is a clear, colorless fluid having a specific gravity of 1.003–1.006. Its reaction may be acid, neutral or alkaline; it has a salty taste and characteristic odor. It contains 0.85–0.91% solids which include 0.65% salts (chiefly NaCl) and 0.24% organic substances (0.12% urea). The amount daily secreted is very variable. The secretion of sweat is closely related to the regulation of temperature (see Chapter XIII).

2. *Secretion of sweat.*—The sudoriferous glands are long unbranching tubules which form at the lower end a globular mass (0.3–0.7 mm in diameter) composed of a coiled tube. The walls of these coiled tubules have a single layer of cuboidal cells.

The sweat secretion is dependent upon the nervous system. Stimulation of the sciatic or brachial nerve of a cat produces sweating of the paw. It is not mere filtration of the blood fluid, but depends upon the specific activity of the gland, as the following facts show. Secretion of sweat does not take place continuously, and twenty minutes after the amputation of a limb, stimulation of the nerve still produces perspiration.

The nerves of sweat secretion after leaving the cord run through the sympathetic and later on join the nerves going to the extremities. The center for the secretion of sweat is supposed to be situated in the cord, for after the cord of a cat has been cut in the cervical region, heat or dyspnœa still produces sweating of the hind legs. A primary sweat centre is supposed to be situated in the medulla oblongata. The secretion of sweat is inaugurated by increase in temperature, asphyxia, poisons (pilocarpin), and also by psychical influences (the sweat of fear). Atropin inhibits the secretion.

9. SEBACEOUS SECRETION

The sebaceous secretion is an oily substance, consisting mainly of cholesterin esters of fatty acids. Concerning its composition but little is as yet known. The sebaceous secretion oils the skin and hair.

The sebaceous glands are composed of a gland body which is formed by a number of saccules. The outer cells of these saccules are small cuboidal cells, while the inner cells are large and spherical and fill the whole saccule and, by their breaking up, form the secretion. The duct leading from the gland to the exterior is formed by the continuation of the outer hair-follicle; it is, therefore, formed from layers of pavement epithelial cells.

Concerning the influence of the nervous system upon sebaceous secretion nothing is known.

10. LACHRYMAL SECRETION

Tears are composed of a clear, alkaline salty fluid. They contain about 1% solids, chiefly salts (NaCl). Proteids are present in small quantities.

The lachrymal glands are built like the albuminous salivary glands. The tears are secreted continuously. Their secretion is, however, under the influence of the nervous system; it is increased by psychical influences (weeping), also reflexly when foreign substances irritate the conjunctiva and by strong light falling upon the eye.

The secretory nerves pass through the lachrymal nerve, the subcutaneous mallar nerve, and the cervical sympathetic.

The tears flow through the ducts of the lachrymal gland in the outer canthus of the eye into the conjunctival sac in the inner canthus and thereby moisten the cornea and the conjunctiva and remove foreign bodies out of the conjunctival sac.

In the inner canthus of the eye the tears are taken up by the puncta lachrymale of the caruncula lachrymalis and then flow through the nasal duct into the inferior meatus of the nose.

II. MILK SECRETION

1. *Composition of milk.*—Milk is a white opaque fluid having an amphoteric reaction, a sweet taste, and a specific gravity of 1.028–1.034. It is an emulsion of fat in which the fat droplets, of 1.5–5μ diameter, are surrounded by pellicles of caseinogen.

The white color and the opaqueness of milk are due to the fact that the light is totally reflected by the fat droplets.

Milk contains 13% solids. The milk of young women contains more solids than that of older women. The solids are:

(*a*) *Proteids* (2.5%), chiefly the nucleo-proteid caseinogen. This proteid is split up by rennin into paracasein a proteid which forms with calcium salts an insoluble double salt (casein) and a soluble proteid (whey proteid).

Besides the caseinogen, the milk contains, in smaller quantities, two proteids which are coagulated by heat: lactalbumin and lactoglobulin.

(*b*) *Carbohydrates* (6%), namely, milk-sugar or lactose (see page 21). When milk stands for a long time the lactose undergoes lactic-acid fermentation (due to bacterium lactis). The lactic acid thus formed precipitates the caseinogen (souring of milk).

(*c*) *Fats* (4%), in fine emulsions, not dissolved. Besides the glycerides of palmitic, stearic, and oleic acid, milk contains the glycerides of the lower fatty acids (butyric, caproic, caprylic acid). On standing, the specifically lighter fat globules rise upward, forming the cream.

(*d*) Cholesterin, lecithin, and a yellow pigment in small quantities. Besides these the milk is said to contain citric acid, a product of the activity of the gland.

(*e*) Salts (0.5%), especially calcium phosphate, also potassium chloride, a little sodium chloride, and a very little magnesium sulphate and traces of iron. The calcium phosphate is present partly in solution as the acid salt and partly in suspension as the neutral salt.

Furthermore the milk contains gases, chiefly carbon dioxide, and less nitrogen and oxygen.

2. *Conditions of the secretion of milk.*—The secretion of milk takes place only during the lactation period which lasts about ten months.

The milk gland consists of 15–20 single tubular glands, each one of which opens by a duct in the nipple. Just before opening at the exterior, the tubules have a sac-like dilation.

The lactiferous ducts have a wall of cylindrical epithelium. The cells of the gland proper form a single layer of epithelial cells, whose height varies greatly. When the ducts are filled with secretion these cells are low, but when the ducts are empty they are cylindrical and filled with numerous fat droplets. The cells of the gland do not perish during secretion, hence only form the secretion and excrete it.

During the first days after delivery there are present in the milk the so-called colostrum corpuscles which are nucleated rudiments of cells containing many fat droplets.

The nervous system has an influence upon milk secretion, for the emotions can alter the quantity and character of the milk. As to the secretory nerves authors differ.

Nourishment has an effect upon the quantity and composition of the milk. A meal rich in proteids increases the proteids and fat of milk; carbohydrate food increases the lactose, but fatty food does not increase the fat of the milk. Caseinogen and lactose are formed in the milk glands, for they do not occur in the blood.

Frequent discharge of the milk from the glands by nursing the child or by milking increases the milk secretion.

CHAPTER VIII

NUTRITION

1. FOODSTUFFS (ALIMENTARY PRINCIPLES)

FOODSTUFFS are substances which the body must take up in order to maintain its material existence, i.e. substances by which the body can rebuild, restore, and replace the parts which have been changed and used up by the vital processes.

We may divide foodstuffs into the following classes:

1. *Those not furnishing energy*, i.e. foodstuffs which cannot impart energy to the body (water and salts).

2. *Those furnishing energy*, i.e. substances rich in potential energy, which by their physiological combustion furnish the body with the energy it needs for its functions. This class includes:

(*a*) Nitrogenous substances—*proteids*.

(*b*) Non-nitrogenous substances—*carbohydrates and fats*.

The energy-yielding substances are sometimes called "foodstuffs" in a narrower sense.

Strictly speaking the inhaled oxygen also belongs to the class of energy-yielding foodstuffs, for it is only by its union with the above-named energy-yielding foodstuffs that their chemical potential energy can be set free and can be used by the body.

The **water** serves to replace the water lost in the secretions, fæces, and expired air. The water formed in the body by the combustion of organic substances containing hydrogen can replace only a small amount of the loss, for the amount so formed is only about 350 cc in 24 hours, while an adult person needs 2–2.5 litres. The amount of water needed is determined by the amount lost in the urine, sweat, and expired air.

The **salts** of the food in part replace the salts taken from the tissue fluid by the excretory organs, and in part furnish material for the formation of organic substances (nuclein, hæmoglobin). The following are the salts necessary as foods:

The *phosphates of the alkalies* are used in the building of the tissues. Only in the presence of potassium phosphate can the cell substance regenerate itself.

Calcium and magnesium phosphate serve chiefly in building up the skeleton.

Salts of iron are used in the formation of the red blood pigment.

The need of iron seems, as a rule, to be completely satisfied by the organic iron (nucleo-proteids containing iron) which is taken up with the other foodstuffs so that no other iron salts need to be taken.

The salts enumerated thus far are found in sufficient quantity in the foods generally taken, so that they do not need to be specially added. The case is, however, different with

Sodium chloride, which not only serves to replace the loss from the body fluids, but serves, at the same time, as a condiment (see page 118) and is therefore eaten in much larger quantities than is really necessary. The average amount of NaCl taken by the adult is about 17 grams, while the real need is only about 2 grams.

The need of sodium chloride is greater among people living upon vegetable food (Negro) than among those eating flesh (Samoids, Tunguses). The reason for this has been sought in the greater amount of potassium salts of the vegetables. The potassium carbonate acts upon the sodium chloride in the body so that sodium carbonate and potassium chloride are formed. These substances are excreted by the kidneys. Hence by the partaking of potassium salts the excretion of sodium and chlorine is increased and therefore more sodium and chlorine must be taken up in the food.

The salts of the foodstuffs not only serve to replace the same salts in the body, but also to form other salts present in the organism which are not taken up with the food (e.g. the alkali carbonates). Continued lack of salt in the food (salt-hunger) results in death, even though food be given in sufficient quantity.

Of the combustible foodstuffs, *proteids* serve to replace the body-proteids destroyed by the physiological combustion. There is no nitrogenous substance, besides proteid, which can supply the body with material for building up its proteids. Hence proteids are absolutely necessary for building up the tissues. But all proteids are not capable of doing this, for the albuminoids (gelatin) cannot entirely replace the proteids of the body. Otherwise it appears that the various true proteids (simple and combined proteids, proteoses) are of equal value as food for replacing the body proteids. At all events, it is not necessary that the same kinds of proteids found in the body should be found in the food. For example, the hæmoglobin and nucleo-albumins in the body, originate, no doubt, from the union of other proteids with iron or phosphoric acid. The albuminoids of the body are also formed from the true proteids, not from the albuminoids of the food.

Proteids contain all the elements needed for replacing organic substances in the body; fats and carbohydrates contain only a part, viz. carbon, oxygen, and hydrogen. Hence proteids alone must be sufficient to satisfy the demand for combustible food for the body. We can, indeed, feed the carnivorous animals on an exclusive proteid diet. This cannot be done with man and vegetable-eating animals, for the quantity of proteid necessary to support life cannot be digested by them.

The **fats** and **carbohydrates** serve as material for combustion which furnishes the body with energy for heat production and for work. In metabolism, gelatin plays the same part. It is often stated that fat serves mainly for heat production, while carbohydrates furnish energy for work, but there is, in this respect, no such fundamental difference between them.

As nutrition on an exclusively proteid diet is at least theoretically possible, we can express the amount of energy-yielding foodstuffs necessary for nutrition in terms of the amount of proteids needed. For a man of 70 kg body weight, the amount of proteids must be about 700 grams a day.

A part of this food must be proteid, it being absolutely necessary. This amounts to about 70 g per day. It has been observed that the body can get along with a much smaller quantity of proteids (40 g per day), but such experiments only lasted for a very short time, hence it is a question whether the body can be nourished for a great length of time with such a small amount of proteid.

After we have supplied the absolutely necessary proteid, the remainder of the food needed can be taken in the form of proteid, gelatin, fat, or carbohydrate or as a mixture of these substances. The proportion in which the foods can, in this case, replace each other is based upon the law of isodynamics, which states that such quantities of combustible foodstuffs as furnish the same amount of energy during their physiological combustion are equivalent (see Chapter XIII). In round numbers the following quantities furnish the same amount of energy: 2.3 g proteid = 1 g fat = 2.3 g carbohydrates.

For an exact application of the law of isodynamics in the practical study of nutrition it must be borne in mind that, in metabolism, the proteids behave differently from the fats and carbohydrates (see Chapter XII).

As a diet, the following is necessary:

	Proteid.	Fat.	Carbohydrates.
Resting man..........	100 g	60 g	400 g
" woman........	90 g	40 g	350 g
Working man.........	130 g	100 g	500 g

The absolute amount needed by old people and children is less. But if the food necessary for each kilogram of body weight is considered, it will be found that children need a larger amount than adults. This is due to two causes: first, a growing body needs relatively more food than an adult, and secondly, the metabolism of children is relatively greater than that of adults because of the greater proportion of surface (thereby greater loss of heat) compared to the heat producing mass (see Chapter XIII).

For one kilogram of body weight the following amounts are necessary:

Age.	Proteid.	Fat.	Carbohydrates.
2–6 years	3.7 g	3.0 g	10.0 g
7–15 years	2.8 g	1.5 g	9.0 g
Adult	1.6 g	0.8 g	8.0 g

Besides the foodstuffs we still take up many substances which are not necessary for the maintenance of the body, but which are, nevertheless, of physiological importance. They are the **condiments.** They include substances having a specific taste and odor which stimulate the nervous system, increase digestion, aid circulation, etc. Under this class we may mention spices and certain alkaloids (caffein in tea and coffee, theobromin in cocoa, nicotin in tobacco).

There are still other organic substances (e.g. vegetable acid, many alcohols) which are also burned in the body and can therefore be regarded as energy-yielding foodstuffs even though they are not necessary for the body. As far as ethyl alcohol is concerned, its worth as a food is doubtful since it acts as a violent poison and its frequent use produces morbid changes in almost all the organs of the body.

2. FOODS

The foods furnished us by nature are mixtures of the foodstuffs. They may be classified as:

1. Food from the animal world.
2. Food from the vegetable world.

The composition of the chief foods is as follows:

PERCENTAGE COMPOSITION OF CERTAIN FOODS.

	Proteids	Fat.	Carbohydrates	Water.	Salt.	Cellulose.
I. Animal Foods.						
Lean beef	20.0	1.5	0.9	76.6	1.0	......
Fat pork	14.5	37.5	0.6	43.6	1.0	......
Shellfishes	17.0	0.5	......	80.5	1.5	......
Salmon	21.5	12.5	......	64.5	1.5	......
Human milk	2.5	4.0	6.0	87.5	0.5	......
Cow milk	3.5	4.0	4.0	87.0	0.7	......
Eggs	12.5	12.0	......	73.5	1.0	......
II. Vegetable Foods.						
Leguminous foods (beans)	24.5	2.0	52.0	12.5	3.5	6.0
Rice	6.5	1.0	78.5	12.5	1.0	4.0
Fine wheat flour	10.0	1.0	72.0	13.5	0.5	0.3
Rye flour	11 5	2.0	69.5	14.0	1.5	1.5
White bread	7.0	0.5	52.5	35.5	1.0	0.3
Rye bread	6.0	0.5	49.0	40.5	1 0	0.6
Potatoes	2.0	0.2	20.7	75.0	1.0	1.0
Cabbage	2.5	0.5	10.5	88.0	1.0	1.5
Asparagus	2.0	0.3	2.5	89.0	0.5	1.0
Fruit	0.5	.....	10.0	85.0	0.5	4.0

Generally the animal foods predominate in proteids and fat. Lean beef consists almost entirely of proteid, and can therefore practically be regarded as a pure proteid food. Butter is nearly altogether fat. Of the animal foods we find carbohydrates only in the milk and, in very small quantities, in the liver (lactose and glycogen respectively).

The vegetables chiefly contain the carbohydrates and but little or no fat. Proteids are found in all vegetables, especially in the legumes.

The following details deserve mention:

The muscles are called **beef.** They consist of the muscle fibre proper and connective tissue; the first contains true proteids, the other a substance yielding gelatin. The real proteid value of meat is determined by the proportion of fibres and connective tissue present.

The amount of fat found in beef varies much and depends upon the feeding.

The manner of preparation (boiling, roasting, etc.) does not alter the value of beef as a food. Boiled beef (meat from which soup is made) has still the same food value as the red or roasted meat, but is slightly less palatable because the extractives which give it taste have been removed. In beef tea (or beef soup) there are, excepting the floating fat droplets and a little gelatin, no combustible foodstuffs and it can therefore not be regarded as a strengthening food. It contains besides the salts (potassium phosphate) the extractives (kreatin, xanthin) which impart to it a delicious flavor and a stimulative activity. It is only a condiment.

Besides the beef of muscle, other animal organs are used as food; some of these also contain large quantities of proteids and gelatin.

Human milk contains more sugar but less proteids and salts than **cow milk.** To render cow milk like human milk (which is necessary for the nursing child), it must be diluted with water and lactose must be added.

The chief proteid of milk is caseinogen. The caseinogen of cow milk is coagulated by rennin in larger flakes than that of human milk and is therefore less accessible to the action of the digestive fluids. Hence children frequently cannot use cow milk. This difference in coagulation is not due to any chemical difference in the caseinogen, but to the different amounts of calcium salts present in the milk.

The calcium salts of milk are used to build up the skeleton of the growing organism.

The cream which rises to the top when milk stands, or which can be centrifugalized from milk, furnishes **butter.** The butter is obtained by beating the cream which breaks the caseinogen pellicles of the fat globules so that the fat globules flow together.

Unsalted butter consists chiefly of fat, 90%, mainly glycerides of oleic, palmitic, and stearic acids and, in smaller quantities, of butyric, caproic, and caprylic acids; it further contains 8% water and casein (2%), lactose and salts. The buttermilk which is left can still be regarded as good food, as it contains much proteid (3–4%) and sugar (4%).

When milk is coagulated by rennin, **cheese** (casein coagulate) is formed; the residue is called whey. The casein incloses the fat globules, and after the whey has been removed it undergoes a putrefactive process, the ripening of cheese. By this process part of the proteids are peptonized, part are decomposed into amido acids; besides this, fatty acids are set free. Cheese is a valuable food because it contains much proteid and fat. Fat cheese contains 25% proteid and 30.5% fat; poor cheese contains 34% proteid and 11.5% fat.

The white of egg contains only egg albumin; the yolk of egg contains, besides the proteids (vitellin), chiefly fat, lecithin, and cholesterin.

All vegetables contain a substance not found in the animal food—**cellulose** or wood fibre. This is but slightly or not at all digested in the intestine of man, but stimulates the peristaltic movements, probably by mechanical stimulation of the intestinal muscles. This causes vegetables to pass through the intestine more rapidly than animal food. The food of the vegetables is inclosed in cellulose coats and hence is not directly accessible to the digestive fluids. By preparing the vegetable foods (grinding, cooking, baking) the cellulose envelopes are burst and the food proper can then be readily acted upon by the digestive fluids.

As a food the vegetable proteid is of equal value to the animal proteid. The carbohydrates of vegetables are generally present in the form of starch, and, to a smaller extent, as sugar (dextrose, fructose, cane-sugar, maltose). Starch is rendered more digestible by boiling, which causes it to swell.

Grinding changes the **grain foods** to fine particles—flour. From this the cellulose envelopes (bran) are removed by sifting. The more bran the flour contains, the richer it becomes in proteid, for the richest proteid layer of the grain lies just below the cellulose envelope. The flour is used in baking bread, etc. The baking is made possible by a proteid, called gluten. The leaven (yeast) added to the dough, produces carbon dioxide by its sugar fermentation which loosens the bread. In many kinds of bread (black bread, graham bread), flour rich in bran is used, and the cellulose of the bran aids the peristalsis of the intestine and prevents constipation.

The **leguminoses** are peculiar because of their large amount of proteid. They contain no gluten and can therefore not be used in baking. They contain, however, a proteid called legumin which forms, when boiled with lime water, an insoluble compound with calcium. Hence they must always be boiled in soft water (containing no lime), otherwise they remain hard.

To obtain nourishment from such foods as greens, cabbage, lettuce, fruits, which are rich in water, a large quantity must be taken. They are therefore not used as a principal food but only as supplemental to others, and serve as condiments because of their flavors. They also furnish the cellulose necessary for the peristalsis.

As to the question whether animal food or plant food is more suitable for man, it may be stated that a mixed diet consisting of one-third animal and two-thirds vegetable food is most suitable. Animal food is not suitable as an exclusive diet because it contains no carbohydrates; on the other hand, the vegetables contain too little proteid and no fat. Also the structure of the digestive organs of man indicates that he is intermediate between the exclusive carnivorous and herbivorous animals. In flesh-eating animals the length of the intestine is about five times that of the body (reckoned from mouth to anus), in the plant-eaters it is more than twenty times this length. The great length of the intestine of herbivorous animals serves to offset the more rapid movement of the food, in order that the food may be sufficiently acted upon and absorbed. As the length of the intestine of man is about ten times that of his body, he is intermediate between the carnivorous and herbivorous animals.

As can be observed in vegetarians, man can indeed be nourished by vegetable foods only, but there are no sufficient reasons for excluding meat altogether from our diet. An exclusive meat diet cannot be endured by man for any great length of time because of the resulting disturbance in digestion.

As many of the foods supplied us by nature are odorless and tasteless, we spice them. The physiological significance of spices lies in the fact that they increase the secretion of the digestive juices, thereby aiding digestion and stimulating the appetite.

Of the various drinks, which are chiefly spices (coffee, tea, cocoa, alcoholic drinks), cocoa may also be considered as a food, because it contains much proteid (12%), carbohydrates (13%), and fat (in cocoa not freed of its fat, 49%). Beer also contains foodstuffs (proteid up to 0.8%, carbohydrates 5–6%), but it can nevertheless not be classified as a food, for, taken in large quantities, the harmful effects of alcohol are manifested. Besides this, the cost of beer is much too high in proportion to its food value.

Certain sensations—hunger and thirst—may be regarded as the stimulations for taking up food and drink. (See Chapter XXVI.)

CHAPTER IX

THE DIGESTION OF THE FOODSTUFFS

By digestion most of the foodstuffs undergo physical and chemical changes by which they are prepared for absorption into the blood. Only a few foodstuffs, e.g. water, salts, grape-sugar, can become part of our body without any change. The most important alimentary principles, proteids, fats, and many carbohydrates cannot be absorbed in the form in whch they are furnished by nature.

The digestion proper is preceded by a mechanical trituration of the solid foods by biting and chewing.

Digestion itself consists of rendering the insoluble or slightly soluble and non-dialyzable foodstuffs soluble and dialyzable. This is brought about by the digestive ferments which, by hydrolytic splitting up, form smaller molecules from the large molecules of the native foods. In this manner proteids are split up into proteoses; starch into sugar; fats into glycerin and fatty acid.

The organ in which the digestion is carried on is the alimentary canal (tractus intestinalis); it consists of mouth and esophagus, stomach, small and large intestine.

1. DIGESTION IN THE MOUTH

1. **Mechanical changes of food in the mouth.**—The mechanical processes in the mouth consist of cutting (biting), chewing, and sucking.

Biting serves to cut off proper portions of the food. The morsel is ground up more or less by **chewing** and, being soaked by the saliva, forms a pulp so that the food is soft, lubricated, and suitable for deglutition.

Biting and chewing are caused by the movement of the upper and lower teeth against each other.

The lower jaw is raised (turning around a horizontal axis passing through both limbs of the jaw) by the masseter, temporal and internal pterygoid muscles of both sides of the head. It is lowered by the digastric, mylohyoid and geniohyoid. During the lowering of the jaw, the hyoid bone must be fixed; this is performed by the omo-, sterno-, and thyro-hyoid and the sternothyroid. The lower jaw is moved forward in a horizontal direction by the two external pterygoids; to the left, by the right external pterygoid; and to the right, by the left external pterygoid. The morsel is held between the teeth, during chewing, by the buccinator from the outside and by the tongue from the inside.

The tongue is pulled forward and downward by the genioglossus, while it is pulled downward and backward by the hyoglossus, and upward and backward by the palato- and styloglossus.

The tongue is composed of vertical, longitudinal, and diagonal fibres. By the combination of their contractions, it can assume many varying positions.

Sucking serves to take up liquid food. By the sucking, a negative pressure is produced in the mouth, and the fluid to be taken up is thus sucked in.

Sucking is produced in one of two ways:

(*a*) By inspiration after separating the nasal passage from the pharyngeal cavity by elevating the soft palate.

(*b*) After the mouth cavity is separated from the pharyngeal cavity by pressing the posterior part of the tongue against the palate, the lower jaw is depressed and the tongue is pulled backward and downward (pure mouth-suction).

The negative pressure in the mouth during pure mouth-suction may, by repeated sucking, be made as low as 700 mm Hg below atmospheric pressure.

2. **Chemistry of digestion in the mouth.**—Digestion in the mouth only affects starch. This is split up by the ptyalin of the saliva, the animal diastase, into sugar.

The animal diastase differs from that of the plants (the sugar-forming ferment of sprouting barley) in that the former is most active at 40°, while the latter acts most energetically at 60°.

Ptyalin is a proteid-like body. It can be obtained for experiments in digestion from fresh or dried salivary glands by extracting the gland with water or glycerin.

Ptyalin acts best in neutral solutions. It is rendered inactive and is destroyed by alkalies and especially by mere traces of free mineral acids. Organic acids only inhibit its activity. Ptyalin is destroyed by temperatures above 60°. Maltose is the chief product in the digestion of starch by ptyalin, only little dextrose being formed. According to later researches, the small amount of grape-sugar is not formed by the direct action of ptyalin upon starch, but is formed from maltose by the activity of a second ferment, glucase. Ptyalin itself forms maltose only.

In this formation of maltose from starch, a number of intermediate products, called dextrins, are formed. These dextrins differ from each other in their behavior towards iodine and are called amylo-, erythro-, and achroö-dextrins, according as they color blue or red or do not color with iodine.

The saliva of carnivorous animals contains no ptyalin; in this case, the saliva only seems to moisten and lubricate the dry food. Mammals living in the water and not eating dry food have no salivary glands.

Saliva also serves to moisten and clean the mouth.

3. **Deglutition.**—By deglutition or swallowing, the chewed food is moved into the stomach.

The bolus is moved from the anterior end of the tongue along the hard palate to the anterior pillars of the fauces. By the stimulation of the sensory nerves ending in the mucous membrane at this part, a reflex action is produced which results in a forcible contraction of the mylohyoid and hyoglossal muscles. By this the bolus is pushed backward into the esophagus.

In order that food shall only escape backward, the pharyngeal cavity must be separated from the mouth, nose, and larynx. This is accomplished as follows:

The opening into the mouth is closed by the posterior part of the tongue being pressed against the hard palate and against the neighboring anterior pillars of the fauces. The nasal cavity is separated from the pharynx by the elevating of the soft palate (by means of the levator palati mollis), by the arching of the posterior walls of the pharynx (by means of the superior constrictors of the pharynx), and by the meeting of the two posterior pillars of the fauces at the median line. The opening into the larynx is closed by the elevation of the larynx by means of the mylohyoid and the geniohyoid and the digastric, to such an extent that it can be covered by the root of the tongue and the epiglottis.

The first act of deglutition here described may occur with so much force that by means of it the food reaches the stomach. This is especially true for liquids and soft foods. Only solid and dry foods remain in the pharynx or upper part of the esophagus till the second step in deglutition carries them downward.

The second part of deglutition consists of a peristaltic movement, that is, a constriction of the esophagus beginning at the top and travelling downward. The pharynx first constricts by means of its constrictors, then the esophagus by means of the constriction of the circular muscles. Thus the parts of the pharynx and esophagus, successively constricted, push the bolus toward the stomach.

The propagation of the contraction from one part of the esophagus to another does not take place by the direct conduction in the muscles, but is dependent upon the central nervous system. After the esophagus has been cut across, the wave of contraction is set up in the lower part when it has ceased in the upper segment.

The innervation of the muscles of the buccal and pharyngeal cavities is brought about by:

1. The third branch of the trigeminus: masseter, temporal, internal and external pterygoid, tensor palati mollis, mylohyoid, anterior belly of the digastric.
2. The facial: muscles of the face, buccinator, posterior belly of the digastric, levator palati mollis, azygos uvulæ.
3. The glossopharyngeal and vagus: stylopharyngeal, constrictors of pharynx and muscles of esophagus.
4. Hypoglossus: the tongue-muscles collectively and the geniohyoid and thyrohyoid.

The nerve centres which govern the processes of chewing, sucking and swallowing lie in the medulla oblongata. (See Chapter XVIII.)

2. GASTRIC DIGESTION

1. **The movements of the stomach.**—Both the cardiac and pyloric openings of the stomach are generally closed by the tonic contraction of the sphincters. During the act of deglutition, the cardiac aperture opens by the relaxation in the tonus of its muscles when the peristaltic contraction has reached the lower end of the esophagus. The pylorus opens and closes to admit part of the contents of the stomach into the duodenum.

The stomach consists of two parts:

(1) The fundus with feeble muscles.

(2) The antrum with strongly developed muscles. The two parts can be separated from each other by a sphincter-like muscle.

Corresponding to the distribution of the muscles, the movements of the pyloric part of the stomach are much stronger than those of the fundus. In the antrum, the pressure caused by the contraction of the muscles may be as high as 130 mm Hg; the pressure in the fundus only 35 mm.

The movements of the fundus serve to mix the food with the gastric juice, the movements of the antrum serve to empty the contents of the stomach into the duodenum.

The length of time during which the different foods remain in the stomach varies greatly. Fluid and soft foods are forced into the intestine soon after being swallowed, but solid food remains for a longer time in the stomach. The last particles of food have left the stomach 7–8 hours after a meal.

Even the excised stomach can execute movements. The normal stimulation for the muscles of the stomach appears therefore to be due to the nerve plexuses in its walls; but the central nervous system influences these movements. There are motor and inhibitory nerve-fibres for the stomach. These fibres run in the vagus and sympathetic and their centres lie in the medulla, the corpora quadrigemina, and the spinal cord.

Vomiting is the emptying of the contents of the stomach after the cardiac sphincter has opened. It is brought about mainly by the contraction of the diaphragm and the muscles in the abdominal walls, by which the intra-abdominal pressure is increased to such an extent that vomiting results. To a limited extent the antrum also takes part in vomiting.

Vomiting is brought about reflexly (stimulation of the sensory nerve in the stomach by abnormal substances) or by drugs which directly affect the vomiting centre in the medulla or by psychical influences (nauseating sights).

2. **Chemistry of gastric digestion.**—When the food has reached the stomach it is still further subjected to the action of salivary ferments (amylolytic period of gastric digestion) for about half an hour. After this, the secretion of the acid gastric juice stops the action of the ptyalin. Then the action of the gastric juice begins.

The active constituents of gastric juice are pepsin, hydrochloric acid, and rennin. The gastric juice digests proteids, inverts cane-sugar, and curdles milk, but does not act upon fats.

(*a*) *Proteid digestion.*—Proteid digestion is brought about by the action of free hydrochloric acid and of the pepsin; by means of these the proteids of the food are split up into albumoses and peptones.

The rôle of the **hydrochloric acid** in proteid digestion is twofold:

First, it causes the proteid body to swell more or less and thereby facilitates the subsequent action of pepsin.

Secondly, in connection with pepsin it causes a peculiar splitting of the proteids.

The hydrochloric acid can by itself split proteids into albumoses and peptones, but to do so the acid must be concentrated, or it must act at boiling temperature or for a long time. Pepsin cannot split up proteids without the aid of hydrochloric acid.

Perhaps the hydrochloric acid is the real splitting agent of the gastric juice, while the function of the pepsin is to render the proteid capable of being split up and it therefore only aids the action of the acid.

The action of the hydrochloric acid is, however, not a fermentative action, as is the case in the formation of sugar from starch where a small quantity of acid can split an unlimited amount of starch. In the proteid digestion, the acid is used up, for it forms with the digestion products the acid proteoses-chlor-hydrates and thus becomes inactive. Pepsin, as ferment, is unlimited in its action.

Pepsin, a ferment of proteid-like composition, is destroyed by heating, by strong alcohol, and by small quantities of free alkali. The last, however, does not act thus in the presence of undigested proteid, perhaps because the pepsin unites with the proteid.

To obtain pepsin, extract the mucous membrane of the stomach, especially that of the antrum, with glycerin or with a 0.2% to 0.4% hydrochloric acid solution.

The intermediate products thereby formed successively by peptic digestion of proteids are:

1. A precipitate formed by neutralizing the solution. Among the first products of peptic digestion, especially in that of coagulated proteids, there is present a proteid coagulated by heat, which, however, soon undergoes a still further change.

2. Primary albumoses, protalbumose, and heteroalbumose, precipitated from neutral solutions by saturation with NaCl.

3. A deuteroalbumose, which is precipitated from acid solutions by saturation with NaCl.

4. A deuteroalbumose, precipitated by saturation with ammonium sulphate.

5. Peptones, not precipitated by ammonium sulphate (see page 37).

During peptic digestion, not all the proteid is completely changed to peptone; the amount of the resulting peptone is, e.g. in case of the crystallized serum albumin of horse blood, only about one-half that of the original proteids; the residue remains in the form of deuteroalbumose.

The individual proteids, including those of vegetable origin, yield proteoses differing but slightly from each other.

The combined proteids are first split up by gastric juice into their components; after this, the proteids thus split off are digested like simple proteids. Nucleins are not dissolved by gastric juice; hence, in the digestion of caseinogen, the insoluble paranuclein remains.

Of the albuminoids, only collagen is digested by pepsin. It is first changed into its hydrate, gelatin, and from this, by hydrolytic splitting up, gelatoses, corresponding to proteoses, are formed.

The process of proteid digestion by gastric juice depends upon:

1. The amount of free hydrochloric acid, the amount most favorable for digestion being 0.2–0.4%.

The acidity of the stomach does not indicate the amount of free hydrochloric acid present because, first, the gastric juice may contain free organic acids, especially lactic acid, and, secondly, the proteoses-chlor-hydrate has also an acid reaction (see page 129). Free hydrochloric acid is present in the gastric juice only when it gives the Günzburg reaction (see page 95).

As artificial experiments in digestion show, the hydrochloric acid can be replaced by other acids, but they are all inferior to it. The lactic acid frequently formed in the stomach by the fermentation of carbohydrates also has digestive action: it is, however, not a normal constituent of gastric juice and therefore its part in digestion is only incidental.

2. Upon the amount of pepsin. The intensity of the digestion increases with the amount of pepsin present till it reaches a certain limit. The increase is proportional to the square root of the concentration of the pepsin.

3. Upon the kind of proteid present and its power of inbibition. Fibrin, which is strongly swollen, is sooner digested than coagulated white of egg, which swells but little. Native proteids are more easily digested than the coagulated, and animal proteid more easily than plant proteid.

4. Upon the temperature. The gastric juice acts best at 37–40° C. At 0° digestion stops, and at 80° the pepsin is destroyed.

5. Upon the presence of the products of digestion. All fermentation processes are hindered and finally arrested by the accumulation of the resulting products. In peptic digestion, the amount of accumulated proteoses must be very large before it completely stops digestion. This influence of the products of digestion is not felt in the stomach because the products formed are rapidly removed.

The products of digestion can also hinder the digestion by uniting with the hydrochloric acid and thereby rendering it inactive. In this case, free hydrochloric acid is lacking and the addition of acid starts the digestion again.

6. Salts can inhibit peptic digestion either by preventing the inbibition or by precipitating the pepsin. This last is also accomplished by alcohol in strong concentration.

Auto-digestion of the stomach.—A piece of the mucosa of the stomach heated in 0.2% hydrochloric acid at 40° C. digests itself. Why normally the mucous lining of the stomach does not digest itself has received no satisfactory answer: it probably depends upon the specific vital character of the epithelial cell of the mucosa.

(*b*) *The inversion of cane-sugar.*—Cane-sugar is inverted in the stomach, i.e. it is split up by the free hydrochloric acid into dextrose and levulose.

(*c*) *The coagulation of caseinogen.*—The caseinogen of the milk coagulates in the stomach, previous to its digestion. This coagulation is brought about by the rennin, which splits the caseinogen up into casein and a soluble proteid called whey proteid. Casein unites with calcium, forming an insoluble compound, cheese. Hence calcium is necessary for the coagulation of caseinogen, and coagulation can be prevented by precipitation of the calcium salts, e.g. by oxalates.

Rennin, a ferment of unknown chemical composition, can act in an acid, alkaline, or neutral medium.

Rennet, used in the manufacture of cheese, can be extracted from the stomachs of calves.

As to the purpose of milk coagulation, see page 143.

Besides the above-named digestive actions, the gastric juice has the special function of disinfectant. Pathogenic and putrefactive micro-organisms, introduced into the stomach with the food, are killed and rendered harmless by the gastric juice. This action is especially due to the free hydrochloric acid, but also to its acid compounds with proteoses.

Nutrition can go on normally after extirpation of the stomach if small quantities of sterilized food are given at frequent intervals. This has been proven in dogs and man.

Hence it has been concluded that the chief functions of the stomach are, first, to disinfect the food and, second, to serve as a reservoir for large quantities of food, which is given out by the stomach to the intestine in such quantities as can be quickly digested. The digestive function of the stomach is, therefore, a secondary affair, seeing that the pancreatic juice alone is sufficient for the digestion of proteids.

3. INTESTINAL DIGESTION

1. **The movements of the intestine.**—During digestion the walls of the intestine make movements, called the peristaltic movements. These consist of periodic constrictions of the intestine brought about by the contraction of the circular muscles. This constriction begins at the pylorus and is propagated to the rectum in the form of a wave. By these movements the chyme is forced from the pylorus towards the rectum and at the same time mixed with the digestive juices of the intestine.

Besides the peristaltic movements, the individual loops of the intestine make movements to and fro, causing the food to be mixed with the digestive fluids.

The cause of the peristaltic movements lies in the intestine itself, for an excised loop of the intestine moves spontaneously. If the intestine is stimulated at a certain point, the contraction begins at this point and spreads itself upward and downward. The contractions are perhaps called forth by the nervous plexures found in the walls of the intestine.

Moreover, the peristalsis is influenced by the central nervous system. The vagus is the motor nerve, and the splanchnic nerve the inhibitory nerve for the circular muscles. Stimulation of this nerve brings about inhibition of the peristaltic movements.

The contraction of the longitudinal muscles of the intestine produces dilation. The splanchnic is supposed to be the motor nerve for the longitudinal muscles, while the vagus is the inhibitory nerve.

2. **Chemistry of intestinal digestion.**—The food, gradually driven from the stomach into the intestine, continues to be acted upon by the pepsin as long as free hydrochloric acid is present. But the free hydrochloric acid is speedily neutralized by the alkali of the secretions which are poured upon the food. There are three secretions: pancreatic juice, bile, and intestinal juice. Of these, the pancreatic juice is the most important for digestion.

A. *Pancreatic digestion.—The pancreatic juice changes starch to sugar, proteids to peptone, and splits neutral fat into glycerin and fatty acids. These actions are brought about by three ferments—amylopsin, trypsin, and steapsin.*

1. *Action of amylopsin.*—Amylopsin splits up starch in the same manner as ptyalin of the saliva. The starch forms successively amylo-, erythro-, and achroö-dextrin, maltose, and finally grape-sugar. The quantity of grape-sugar formed is somewhat larger than that formed by ptyalin, perhaps because the pancreatic juice contains more glucase than the saliva.

2. *Tryptic digestion.*—Trypsin splits up proteid. It can act in an acid medium, but acts best in an alkali medium. This proteid digestion differs from peptic digestion in the following particulars:

(*a*) The proteid digestion by trypsin is carried further than that by pepsin. Peptic action stops at the formation of peptones, but trypsin splits some proteids up into leucine, tyrosine, and aspartic acid (see page 27). The peptones which can be split up by trypsin are called hemipeptones;

those not capable of such splitting up are called antipeptones.

(*b*) While pepsin digests collagen but not nuclein, trypsin digests nuclein but not collagen. Gelatin, however, is readily digested by trypsin. The gelatin peptones are not split up by trypsin into amido-acids. Elastin is not digested by pepsin, but readily by trypsin.

(*c*) The products of proteid digestion by pepsin, injected into the blood stream, stop the coagulation of the blood; not so the products formed by tryptic digestion.

(*d*) The rotatory power of the collective products formed by peptic digestion is greater than that of the undigested proteid, while the rotatory power of the products of tryptic digestion is smaller.

(*e*) In the presence of free hydrochloric acid, pepsin digests trypsin, but in an alkali solution trypsin does not digest pepsin.

Trypsin is not digested by pepsin in the intestine, because the free hydrochloric acid, in so far as it is not united with the proteoses, is neutralized by the alkali of the intestinal juices.

During proteid digestion by trypsin the same intermediate products arise as by peptic digestion. From coagulated proteids there is formed in considerable quantities a soluble proteid, coagulable by heat. Protalbumose and heteroalbumose are not formed, but deuteroalbumose is directly formed.

To obtain trypsin for experimental work, heat the pancreas with highly dilute acetic acid and extract the ferment with glycerin. Trypsin is not found in the pancreas in the form of active ferment, but as zymogen. This zymogen is transformed into the active ferment by dilute organic acids. The secretion obtained by a pancreatic fistula often contains only zymogen, which is converted into active trypsin by coming into contact with the acid chyme.

3. *Action of steapsin.*—Steapsin of pancreatic juice is a ferment which, by hydrolytic splitting up, changes neutral fats into glycerin and free fatty acids. When alkali carbonate is present in the intestine, soluble soaps are formed from the fatty acids.

It has not yet been determined to what extent fats are split up. Till recently it was maintained that only a small part of the fat is split up and that the large residue was emulsified by the soap formed (see page 24) and absorbed in the form of emulsion. Recently it has been supposed that all the fat is split up before it is absorbed. After the extirpation of the pancreas the absorption of fat is decreased. In this case, however, fats are still split up by putrefaction in the intestine.

B. *The function of bile in the digestion.*—Bile contains no ferment, hence it does not digest, but aids in the processes of digestion.

1. By aiding in neutralizing the free hydrochloric acid. This stops the action of the pepsin upon the trypsin.
2. By aiding the action of pancreatic ferments.
3. By dissolving the free fatty acids.

Besides this, bile plays an important part in the absorption of fats (see Chapter X).

Some authors ascribe an antiseptic action to bile, but others deny this.

C. *Digestion by the intestinal juice.*—Intestinal juice contains, besides a diastatic ferment, an inverting ferment which changes cane-sugar into dextrose and levulose. Intestinal juice also splits up lactose, this not being absorbed as such. This action of the intestinal juice is supposed to be due to a ferment called lactase.

The accounts of other ferments in the intestinal juice are contradictory.

The intestinal juice, by its alkalinity, favors the action of the pancreatic ferments and, by its mucin, favors the movements of the chyme and the formation of fæces.

4. PUTREFACTION IN THE INTESTINE

In the intestinal canal, especially in the lower part of the small intestine, processes of putrefaction, due to micro-organisms, take place. These processes change the contents of the intestine chemically.

The changes brought about by the putrefaction are, in many respects, similar to those produced by digestion; in other respects, they are very different.

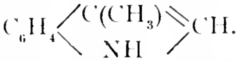
From **proteids** there arise by putrefaction:

1. Albumoses and peptones.
2. Fatty acids, amido-acids, and ammonia; by the putrefaction of gelatin, glycocoll is also formed.
3. Phenol, paracresol, indol, skatol, phenylpropionic acid, phenylacetic acid, paraoxyphenyl-acetic acid, paraoxyphenyl-propionic acid.

Indol, C_8H_7N, has the following constitution:

$$C_6H_4\begin{cases} CH \\ NH \end{cases} CH.$$

Skatol, C_9H_9N:



$$C_6H_4\begin{cases} C(CH_3) \\ NH \end{cases} CH.$$

Part of the aromatic products of proteid putrefaction are absorbed; they are then in part oxidized (indol forming indoxyl, skatol forming skatoxyl). The aromatic oxy-acids are not changed, but phenol, indoxyl and skatoxyl are excreted by the urine as conjugated sulphates.

4. Gases: carbonic acid, hydrogen, marsh gas, and sulphuretted hydrogen.

Putrefaction, therefore, like tryptic digestion, forms proteoses and amido-acids from proteids. But by putrefaction there are also formed aromatic decomposition products (phenol, oxy-acid, indol, and skatol), which are not formed by the action of trypsin.

Fats are split into fatty acids and glycerin by putrefaction. The fatty acids are in part still further decomposed into the lower fatty acids.

From the **carbohydrate,** alcohol, lactic, acetic, and succinic acids are formed by putrefaction. Part of the starch is first changed to sugar. The indigestible cellulose is also acted upon by putrefaction; this, however, does not form sugar but organic acids (acetic, valerianic acid, etc.), carbonic acid, and methane. By this decomposition of the cellulose, the food inclosed by it can be acted upon by the digestive fluid.

Concerning the putrefactive decomposition of the constituents of the digestive fluids, the following may be said: dyslysin is formed from cholalic acid; stercobilin, the coloring matter of fæces, from bile pigments.

5. THE FORMATION OF FÆCES AND THE UTILIZATION OF FOODSTUFFS

1. **Composition of fæces.**—The undigested, unabsorbed residue of the food and the useless constituents of the alimentary secretion are called **fæces** and are discharged through the anus.

The fæces contain:

1. Undigested and unabsorbed constituents of the food, such as remains of plants, keratin, nuclein, muscle-fibres, connective tissue, lumps of casein, starch granules, fat, hæmatin.
2. Residue of digestive juices, e.g. cholalic acid, dyslysin formed from bile acids, bile pigments, cholesterin, mucin.
3. Cast-off epithelial cells and their decomposition products.
4. Products of putrefaction: skatol, indol, iron sulphide, fatty acids. Along with the fæces, the gases formed by putrefaction (marsh gas, sulphuretted hydrogen) are discharged.
5. Mineral matter of the food and of the intestinal secretions.

Finally, there are present in the fæces parasites of various kinds.

The reaction of the fæces may be neutral, acid, or akaline. Its odor is due to the skatol, indol, and other volatile substances. The color is generally light or dark brown; the pigment is the stercobilin produced by putrefaction from bilirubin.

In the large intestine the fæces become solid by the absorption of water, and here it is formed into balls.

The amount of fæces daily discharged is about 120–150 grams, containing 30–37 grams solids.

2. **Utilization of foodstuffs.**—As the fæces contain undigested food, not all the food taken into the alimentary canal is utilized by the body. The amount utilized by the body can be found by subtracting the undigested food present in the fæces from all the food taken by the mouth. As the amount of undigested food in the fæces has never been definitely determined, no accurate figure of the amount of food absorbed can be given.

The amount absorbed must be taken into consideration in formulating a diet. The animal foods are better absorbed than the vegetable foods. There are absorbed:

	Proteid	Fat.	Carbohydrate.
of meat and eggs.....	97%	95%	—
" milk	89–99%	95–97%	100%
" white bread.......	78%	—	99%
" black bread.......	68–78%	—	89%
" potatoes..........	68%	—	92%
" turnips...........	61%	—	82%

The reasons why vegetable foods are so poorly absorbed are:

(1) The food in vegetables is often inclosed in cellulose membranes which prevent the action of digestive juices upon the food. Hence vegetable foods are the better absorbed in proportion as they are free from the cellulose membrane in their preparation.

(2) The cellulose stimulates, perhaps mechanically, the peristalsis. Vegetable foods are therefore more quickly carried through the intestine than the animal foods; in fact, so rapidly that they are discharged as fæces before they have been fully acted upon and absorbed.

(3) **Defæcation.**—The anus is kept closed by the tonic contraction of the sphincters ani, internus and externus. The action of the external sphincter is increased by the voluntary contraction of the levator ani, which is placed like

a sling around the rectum. During defæcation the tonus of the sphincters is inhibited, thus allowing the fæces to pass out. The defæcation is produced by the peristalsis of the rectum, aided by abdominal pressure. The muscles producing this pressure are the diaphragm and the muscles of the abdominal walls.

The centre of defæcation is situated in the lumbar cord. It is stimulated reflexly from the rectum. The inauguration of the reflex depends, to a certain extent, upon the will. The nerves going from the centre to the muscles of the rectum run through the hypogastric plexus and the sympathetic (ganglion mesentericum posticus) and the nervi erigentes. The first-named nerves are supposed to be motor nerves for the circular muscles and inhibitory nerves for the longitudinal muscles; the last-named are supposed to be motor nerves for the longitudinal muscles and inhibitory nerves for the circular muscles.

Defæcation takes place in man at least once a day.

CHAPTER X

ABSORPTION AND ASSIMILATION OF FOODSTUFFS

1. GENERAL REMARKS ABOUT ABSORPTION AND ASSIMILATION

UNDER **absorption** we include the processes whereby the dissolved foodstuffs and the emulsified fats are taken up from the mucous lining of the stomach and intestine and are brought directly or by means of the lymphatics into the blood, by which they are carried to the organs and tissues of the body.

By **assimilation** we understand the processes which the absorbed foodstuffs undergo till as constituents of the cells and tissues they are consumed in the activity of the tissues.

As the insoluble and undialyzable food is rendered soluble and dialyzable by digestion, it is probable that osmosis of the soluble substance plays an important part in absorption. Still there are certain facts about absorption which cannot be explained by the laws of osmosis as known to us at present. Absorption often takes place contrary to the laws of osmosis. On the one hand, water is absorbed from a sodium chloride solution placed in the intestine even though of higher osmotic pressure than the blood, whereas, according to the laws of osmosis, water ought to pass from the blood or lymph into the intestine. On the other hand, undialyzable substances, like proteid and emulsified fat, are taken from the intestine by the blood.

The force which causes this absorption contrary to the laws of osmosis is due to the activity of the epithelial cells. This view is supported by the fact that when the intestinal epithelial cells are rendered functionless by sodium fluoride (which does not destroy the cells anatomically), absorption follows the law of osmosis.

The **seat of absorption** is chiefly the intestine; in a less degree, the stomach. Pure water is not absorbed from the stomach; on the contrary, water is passed by the mucous lining into the stomach. Aqueous solutions of salts, sugar, and peptones are absorbed when they are very concentrated. Absorption from the stomach is favored by table-salt and spices, such as mustard, peppermint, pepper. Alcohol and other narcotics also favor absorption because they paralyze the resistance which the epithelium of the stomach offers to the absorption of foodstuffs.

Most of the absorption takes place in the *small intestine*, where the surface for absorption is very large. The villi of the mucous membrane of the intestine increase the absorption surface to twenty-three times what it would be if no villi were present. One sq. cm. of the intestinal mucosa contains about 2500 villi.

The epithelial cells of the intestinal mucosa are cylindrical. The free surface of these cells is striated. Each villus contains a central lacteal, and between this lacteal and the outside border of the villus are the blood vessels, a mass of capillaries, and the afferent and efferent vessels. The lacteal is surrounded by smooth muscle-fibres, by the contraction of which the villi are shortened, the lacteal is pressed together, and the contents emptied into the lymph vessels.

In the *large intestine* also considerable absorption takes place. Among other things water is here absorbed whereby the contents of the intestine become more solid. Food is also absorbed in the large intestine when, in soluble form, it is forced through the anus into the intestine as nutritive clyster.

The **path of the absorbed food** from the intestine is twofold: (1) The portal vein; (2) the lymph vessels.

Water, salts, sugar, and proteids are absorbed by the portal vein; fats are absorbed by the lymphatics. After the water, salts, and sugar have traversed the epithelial layer, they pass into the closely adjoining blood capillaries. Thence they are carried with the blood through the portal vein. When great quantities of fluids have been taken, a part may reach the lymph vessels. It has been observed in animals that the lymph in the thoracic duct is increased only when a large quantity of water is imbibed, and that the carbohydrates in the lymph are increased only during the absorption of a large quantity of concentrated sugar solution. The blood of the portal vein, however, always contains, during absorption of carbohydrates, more sugar than arterial blood. Observations upon human beings with thoracic duct fistula, from which all the lymph from the intestine flows, show that the lymph contains at best only traces of the absorbed sugar.

That the absorbed proteids are carried through the portal vein is proven by the facts that ligaturing the thoracic duct does not interfere with the proteid nutrition and metabolism, and that the lymph flowing from a thoracic duct fistula, as mentioned above, shows no increase of proteids during their absorption.

Fats, on the other hand, are mostly absorbed by the lacteals. During the absorption of fats the lacteals and the thoracic duct appear white, because of the milky turbulence due to the absorbed emulsified fat. But as all the fat eaten cannot be demonstrated in the lymph flowing from the thoracic duct or from a chylus fistula during the absorption of fat, it has been assumed that part of the fat is absorbed by the blood vessels.

2. ABSORPTION AND ASSIMILATION OF PROTEIDS

Before proteoses are absorbed into the blood, they undergo a change in the wall of the intestine. The blood of the portal vein and the lymph contain no proteoses. If proteoses are injected into the blood, they are rapidly excreted by the kidneys.

The change from proteoses to simple proteids takes place in the epithelial cells of the intestine, for the native proteids of the body are increased when no other proteids than proteoses are given in the food. Hence the real body proteid must have been formed from the proteoses of the food.

If a solution of proteoses is heated at body temperature with the fresh mucous lining of the intestine, the proteoses gradually disappear without the further formation of decomposition products. This supports the view that the proteoses are changed back to native proteids.

Solutions of native proteids, acid and alkali albumin can also be absorbed as such without previous digestion. It has been observed that such proteids, placed in an isolated loop of intestine free from ferment, are rapidly and completely absorbed without albumoses and peptones having been formed. These proteids, injected into the blood are assimilated and used by the body; this, however, is not true of caseinogen, egg albumin, and hæmoglobin, for they are rapidly excreted by the kidneys if injected into the blood.

Large quantities of egg albumin solution taken into the stomach can also be absorbed without previous digestion, but are then excreted by the kidneys. Caseinogen and hæmoglobin are precipitated in the stomach and are therefore not absorbed without digestion and the transformation into new proteid in the intestinal wall. This perhaps explains the meaning of the caseinogen coagulation by rennin, for, if the caseinogen was not precipitated, it might be absorbed as such and then be excreted by the kidneys.

Many soluble proteids can, therefore, be absorbed and assimilated and used in the body without being digested or changed; others, on the contrary, must first be digested. The object of digestion is therefore, first, to render insoluble proteids soluble and, secondly, to change the proteids which are soluble but cannot be assimilated to proteids which can be assimilated.

Proteids which are soluble and can be assimilated are, without doubt, also digested, but the extent of this digestion cannot be stated. The digestion of proteids capable of assimilation is, however, of real significance, since their rate of absorption is thus increased.

Absorbed proteids reach the blood, most likely, chiefly in the form of albumin, as the quantity of serum albumin of the blood is increased by the eating of proteids.

Concerning the further history of proteids and assimilation nothing is known.

3. ABSORPTION AND ASSIMILATION OF FATS

From the fatty acids or soaps and glycerin formed by the splitting up of fats during digestion, neutral fats are again formed in the mucosa of the intestines. Even if fatty acids or soaps are eaten, neutral fat is present in the lymph; in this case the glycerin necessary for the formation of neutral fats must have been formed in the intestinal wall itself. If a mixture of soap and glycerin is heated with the intestinal mucous membrane, neutral fats are also formed. This formation of neutral fats takes place in the epithelial cells. During the digestion of fats the epithelial cells of the intestine are filled with fat droplets of various sizes.

But the fat found in the epithelial cells is not necessarily derived from the union of the fatty acid and glycerin taking place in these cells; for neutral fats in the emulsified state may be taken up by them directly.

The opinion is current that most of the fat is absorbed in the emulsified condition, and that only such a quantity of fat is split up as is necessary to furnish the fatty acids or soap needed for this emulsification. But the correctness of this view is doubtful because the other necessary condition for emulsification—the alkaline reaction of the contents of the intestine—is frequently wanting. The contents of most of the upper part of the small intestine have an acid reaction due to free fatty acids; yet here fats are also absorbed, as is shown by the milky contents of the lacteals. Hence it is difficult to decide in how far the splitting up and emulsification of fats take place.

The absorption of emulsified fat is supposed to be brought about by the active movements of the striated border of the epithelial cells.

The absorption of fats is aided by the bile. Animals with a biliary fistula absorb but little of the fat eaten. This favorable action of bile is supposed to be due to the fact that it dissolves free fatty acids and the insoluble calcium and magnesium soaps, and that the striated border of the epithelial cells is, by the bile, rendered permeable for the emulsified fat. Both these actions are attributed to the bile salts. The soda of the bile also aids in the emulsification of fats.

If, by pancreatic extirpation, the steaptic digestion is prevented, the amount of fat absorbed is greatly reduced. This, however, is not true for the fat of milk, for this is already in a finely emulsified condition.

From the epithelial cells the emulsified fat is transferred to the lymph and with this is carried through the thoracic duct into the blood. The fat, in so far as it is not directly oxidized, is stored up in the cells of the adipose tissues of the body.

The amount of fat in the blood is somewhat greater during fat absorption than during fasting. During starvation the amount of fat in the blood is also increased, for then the fat stored up in the tissues is transported by the blood to the place of combustion.

Immediately after a meal rich in fat, large quantities of fat appear in the liver cells (physiological filtration of fat), which disappear after a short time.

4. ABSORPTION AND ASSIMILATION OF CARBOHYDRATES

The monosaccharides are carried by the portal vein to the liver without having undergone any change in the walls of the intestine.

Cane-sugar and lactose are generally not absorbed as such, but are split up into their simple sugars. Only when they are taken in very large quantities are they absorbed as such into the blood, but are then excreted by the kidneys.

In the liver, the monosaccharides are changed to glycogen and stored up in this form (see page 23). The object of this glycogen formation is to prevent the sugar from too great accumulation in the blood; for if the percentage of sugar in the blood rises above a certain limit (0.2%), the excess is excreted by the kidneys.

The per cent of sugar in the portal vein during absorption of carbohydrates is greater than that in arterial blood or in blood from the hepatic vein.

Glycogen can be formed from dextrose, levulose, and galactose. The glycogen formed from levulose and galactose is identical with that formed from dextrose. When glycogen is formed from levulose and galactose, they are first changed to dextrose, for in the splitting up of glycogen only dextrose results.

The amount of glycogen in the liver depends upon the nutrition and upon the amount of material used up by the body. After a long fast and also after severe muscular work and strong cooling of the body, the liver is free from glycogen. After a meal rich in carbohydrates the liver of a rabbit contains as much as 17% glycogen. In the liver of a criminal executed shortly after a meal, 6% glycogen was found. A liver free from glycogen is small and has a dark brown color, while the liver rich in glycogen is large and has an ochre color. A liver rich in glycogen may weigh three times as heavy as one poor in glycogen; this is not only due to the larger amount of glycogen, but also to the large amount of other solids and of water present.

The glycogen is stored up in the cells in the form of flakes. It can be obtained from the liver by cutting the liver into small pieces and boiling in water to which a little acetic acid has been added. By this the proteids are coagulated and the glycogen is dissolved, forming an opalescent solution from which it may be precipitated by alcohol.

When needed, the glycogen in the liver is again transformed into dextrose which is carried out by the venous blood to the tissues. At this time the per cent of sugar in the blood of the hepatic vein is greater than that in the arterial blood or blood from the portal vein. Both the formation of glycogen and its reconversion into sugar are brought about by the liver cells.

Carbohydrates in the form of glycogen are also stored up in the muscles, and are used up when needed, e.g. during muscular activity. The muscle-glycogen is supposed not to be identical with that formed in the liver. At all events the glycogen of the muscles is not derived as such from the liver.

When the carbohydrates in the food are present in excess, the body, by reduction and synthesis, forms fat from them and thus stores them up.

In **diabetes mellitus** the glycogenic function of the liver is disturbed. This causes sugar to accumulate in the blood to such an extent that it is excreted by the kidneys. We can discriminate between two forms of diabetes, a mild form, in which sugar appears in the urine only when carbohydrates are eaten, and a severe form, in which sugar is excreted even if no carbohydrates are eaten. In the latter case the sugar is derived from the proteids. Nothing is positively known concerning the immediate cause of diabetes. Artificial diabetes may be produced:

1. By the so-called diabetic puncture (Piqûre) whereby a part of the medulla at the lower end of the calamus scriptorius is destroyed. This seems to prove that the glycogenic function of the liver is dependent upon the central nervous system.

2. By extirpation of the pancreas (see Chapter XI).

3. By various poisons: phloridzin, curare, phosphorus, corrosive sublimate.

The amido-acids (leucine, tyrosin, etc.) formed from the hemipeptones by pancreatic digestion are also absorbed, and in the liver they are changed to urea.

The products of putrefaction, phenol, aromatic oxy-acids, indol and skatol are also absorbed in part, but are excreted by the kidneys (see pages 51, 104 and 136).

Besides the products of digestion of foods, some of the constituents of the digestive fluids are absorbed, e.g. the bile salts, which, arriving at the liver, stimulate the bile secretion. The digestive ferments, pepsin and ptyalin, when absorbed, are excreted by the kidneys, while trypsin and steapsin are destroyed in the blood.

According to another view, the ferments excreted by the kidneys are not derived from the intestine, but are absorbed, in the form of zymogens, by the blood from the glands between the periods of digestive activity.

Other mucous membranes, besides those of the stomach and intestine, are able to absorb dissolved substances, but such absorption is of no physiological importance.

The skin can absorb small quantities of certain substances.

Subcutaneous injection of foodstuffs.—Many foods can be used by the animal economy when, in proper form, they are directly introduced into the tissue fluids. This is true in case of subcutaneous injection of native albumin, fat, or dextrose.

CHAPTER XI

THE CHANGES OF BLOOD IN THE ORGANS. INTERNAL SECRETION

FROM what has been said in the foregoing chapters, it follows that the blood streaming through an organ is changed not only in respect to its gases but that it must undergo other changes as well. In the organs in which the physiological combustion takes place, e.g. in the muscles, the blood supplies the material for this combustion and acquires, besides the carbon dioxide, other products of combustion, especially those containing nitrogen. In the glands the blood loses substances from which the secretions are formed; in the walls of the intestine it takes up the absorbed foods; in the liver and in the adipose tissue it either deposits the carbohydrates and fats or, if necessary, takes them up. Moreover, the blood as a tissue (see page 52) has its own metabolism, by which it is chemically changed. The above-mentioned changes in the blood have, in some cases, been demonstrated. But in most cases a difference cannot be detected, because the amount of the substance given up or acquired by the blood in flowing through an organ is so small in proportion to the amount of blood flowing to and from that organ that it lies within the limits of error of observation.

Besides the changes in the blood which we can understand from the known physiological properties of the organ, it undergoes still other changes, concerning the nature and significance of which very little is known. Many organs appear either to alter deleterious substances found in the blood, by changing them into harmless products, or by forming and giving up to the body substances which influence either the metabolism or act upon the nervous or muscular system. This process is called "internal secretion," since these organs throw their products into the blood.

Among the organs which have an internal secretion are all the blood glands, the thyroid and suprarenal glands, the liver, the pancreas, and perhaps the testes.

Among the blood glands are also classed the spleen and thymus gland, whose function is not so much a secretion as the formation and destruction of blood corpuscles (see pages 88 and 89).

I. **The thyroid gland.**—The thyroid gland contains in its connective tissue many completely closed vesicles. The walls of these vesicles are formed by a single layer of cuboidal cells and the vesicles are filled with a "colloid" substance. The thyroid gland must be regarded as a true ductless gland, the cuboidal cells being the secreting gland-cells; the colloidal contents of the vesicles, the secretion. The contents of the vesicles are emptied into the lymph spaces between the vesicles and are thus carried to the blood.

After the thyroid gland has been excised for goitre, a series of severe disturbances has been observed which sooner or later end in death (cachexia strumipriva). Diseases of the nervous system (diminution of psychical functions, idiocy, and motor and sensory paralysis or spasms), degeneration of the liver and kidneys, disturbances in metabolism and in the regulation of body heat set in. These phenomena are also present during disease of the thyroid gland, when œdamentous swelling of the skin and idiocy are especially marked (myxœdema). In dogs, extirpation of the thyroid gland produces death in a few days, preceded by strong spasms and severe disturbance in nutrition. In rabbits, extirpation of the thyroid is generally not fatal, but leads to changes in metabolism, myxœdemous swelling of the skin, scaly eruptions, and shedding of the hair.

The injurious effects of extirpation or disease do not appear when a small part of the gland is retained or when the thyroid gland is transplanted to the peritoneal cavity or when fresh or dried thyroid glands are given by mouth. The abnormal enlargement of the thyroid (goitre) can also be relieved by feeding on thyroid glands.

One of the most striking effects of the therapeutical use of thyroid preparation is the rapid fall in body weight and the disappearance of body fat. This loss of weight is due, as has been shown by experiments in metabolism, partly to the withdrawal of water from the tissues, the water in the urine being increased, and partly by the not inconsiderable increase in combustion. By feeding a rabbit sufficiently with thyroid glands, the combustion processes can be doubled. The combustion of proteid, is, however, little affected as long as non-nitrogenous material, especially fat, is present.

The thyroid gland is therefore indispensable for life. Most likely its importance lies in the fact that it produces one or more substances which are absolutely essential for the normal course of life's processes. An excess of these substances produces severe disturbances in the nervous system and metabolism, and can also produce death. From the thyroid gland there has been isolated a substance containing iodine, thyroiodin, which is believed to be the active principle of the gland, for iodine has a certain therapeutical action upon hypertrophic thyroid glands. But, as all thyroid glands do not contain this substance, and as thyroiodin does not show all the actions of the thyroid gland, we can hardly regard it as the active substance.

The thymus is supposed to have the same function as the thyroid gland, for feeding on thymus is said to have the same result as feeding on thyroid glands.

II. **Suprarenal capsules.**—The suprarenal capsules consist of cellular parenchyma surrounded by connective tissue capsules. The parenchyma forms a clear cortical and a dark red medullary portion. In both the cortical and the medullary portion numerous nerve elements (non-medullated nerve fibres, sympathetic ganglionic cells) are present. Because of this abundance of nerve elements, the suprarenal capsules have been regarded as nervous organs for the inhibition of peristaltic movements of the intestine.

As extirpation of the suprarenal capsules results in a general paralysis and finally death, they must be regarded as vital organs. The injection of an aqueous extract of suprarenal capsule is said to remove the effects of extirpation. This aqueous extract contains two substances, whose chemical nature is not yet known. Of these the one causes a considerable increase in blood pressure, while the other can decrease the pressure but works more feebly than the first. This increase in blood pressure caused by the first-mentioned substance is due to a general contraction of the small arteries. The anatomical part upon which this substance acts lies in the walls of the blood vessel itself. It paralyzes the central nervous system. It stimulates not only the muscles of the blood vessels but also the skeletal muscles; hence its function seems to be to increase the tonus of the muscles, both of the skeletal and of the blood vessels.

Concerning the manner in which the second substance acts nothing certain has yet been determined.

Pathological changes in the suprarenal capsules are followed by an abnormal coloring, bronzing, of the skin (which is also said to follow the extirpation of the suprarenal capsule). This is called Addison's disease.

The active substances of the suprarenal capsule extract are rendered inert by passing them through the liver.

III. **The liver.**—Besides functioning in the

(1) Secretion of bile (see page 99),

(2) formation of glycogen (see page 146), and

(3) breaking up and formation of red blood corpuscles (pages 54 and 100),

the liver also has the important function of

(4) changing the ammonia salts, produced by proteid metabolism, into urea (in mammals) or into uric acid (in birds and reptiles). (See pages 45 and 47.)

If the liver is isolated from the circulation by joining the portal vein directly with the inferior vena cava, the urine excreted contains less urea and more ammonium salts than normally and the animal shows symptoms of poisoning characteristic of the ammonium compounds. Extirpation of the liver in birds is followed by the appearance of ammonia and lactic acid in the urine instead of uric acid.

The object of this change which the ammonia salts undergo in the liver seems to be to change the poisonous ammonia into harmless substance.

The liver, inserted as a filter between the capillary network of the portal vein, acts upon the substances absorbed from the intestine. In the first place, it changes the injurious products of proteid putrefaction, phenol, skatol, indol, into the harmless ethereal sulphates which are excreted in the form of alkali salts. In the second place, the liver retains the vegetable and animal poisons (alkaloids) incidentally introduced into the alimentary canal; these poisons are destroyed and excreted with the bile. In the third place, metallic poisons (arsenic, antimony, lead) are deposited in the liver and the body is thus shielded from their injurious effect. These poisons are also finally excreted.

The anatomical relation between the spleen and the liver (the splenic vein is a branch of the portal vein) points to a physiological relation between these two organs. Perhaps the hæmoglobin set free in the spleen by the breaking down of the red blood corpuscles is decomposed in the liver.

In the rabbit many lobes of the liver can be removed without any disturbance being noticed. The extirpated lobes are soon replaced.

IV. **The pancreas.**—Besides the secreting of pancreatic juice, the pancreas plays an important part in the metabolism of carbohydrates. After extirpation of the pancreas the carbohydrates are no longer properly oxidized in the body and hence are largely excreted with the urine (pancreatic diabetes). If a small part of the pancreas is left, no diabetes results. On the other hand, injection of pancreatic juice or feeding with pancreas does not stop the diabetes, but increases it. Extirpation of the pancreas causes the liver to lose its power of forming glycogen, and the tissues their power of oxidizing sugar.

V. **The testes.**—In addition to their function as reproductive organs, the testes stand in close connection with the whole body. This connection is, no doubt, brought about by substances furnished by the glands to the blood, which modify the vital processes. Extirpation of the testes (castration) in a boy is followed by disturbances in development. The voice does not change at puberty, the muscles remain soft, and there is no development of manly strength and character. Also in adult man, castration, or premature atrophy of the testes, is followed by disturbances in the nervous system and psychical life. It is said that subcutaneous injection of testes-extract increases manly strength and thereby increases the bodily and psychical well-being. Nothing is known concerning the nature of the active substance.

Functions of a similar nature to those of the above-described organs have been attributed to the ovaries, prostate, hypophyses, and kidneys, but nothing certain is known about them.

CHAPTER XII

METABOLISM

WHILE we have thus far considered the individual substances taken up and cast out by our body and have explained their importance, we shall now treat of the balance, or the comparative composition of the quantities of the substances taken up and cast out by the body collectively. This balance not only gives us the extent of metabolism, but also shows us the relation and the use of each foodstuff to the animal economy. At the same time we can thereby learn how a person can best support himself with the most appropriate food at the least expense and how to bring his body to a desired state of nutrition. Upon the results of this balance of metabolism is based the practical science of dietetics.

1. METHODS OF INVESTIGATION IN METABOLISM

To strike a balance of nutrition, we must know the quantity taken up and given off.

The substances taken up are food and the inhaled oxygen.

The substances cast out of the body are found in the urine, fæces, sweat, expired air; smaller amounts in the sebum of the skin, in the cast-off horny epithelium, hairs, nails, at times in the menstrual blood, milk, and semen. Of these, as a rule, only those present in the urine, fæces, and expired air are taken into account in the balance of nutrition. The others are present in such small quantities that they do not need to be considered or are excluded by the condition of the experiment.

The ideal experiment in metabolism would be to estimate quantitatively each individual constituent of the incomings and outgoings and to use the results in striking the balance of nutrition. But this is impossible because of unavoidable difficulties in the methods of investigation. But to form a correct conception of the extent and nature of the metabolism, it is sufficient to know the amount of some of the constituents or even some of the elements of the income and outgo. Of these elements the most important are the carbon, nitrogen, the oxygen of inhaled air, and frequently the sulphur and phosphorus.

The **nitrogen** both of the income and outgo can be directly determined by Kjeldahl's method, by which the nitrogen of the substance to be analyzed is changed, by boiling with concentrated sulphuric acid and mercury, into ammonia, and as such it may be measured.

The **carbon** of the income and of the urine and fæces is determined by analysis. The expired carbon is calculated from the amount of carbon dioxide exhaled.

The inhaled **oxygen** is either determined directly from the amount of oxygen taken from the respired air or calculated from the other data of the balance of nutrition.

The taking up of oxygen and the giving off of carbon dioxide is called "*respiratory metabolism.*"

For investigating the respiratory metabolism, we may use the apparatus of: (1) Pettenkofer-Voit, (2) Regnault-Reiset, or (3) Geppert-Zuntz.

By the Pettenkofer-Voit apparatus the gaseous outgo of carbon dioxide and water vapor is determined directly. This is done as follows: A person breathes in a hermetically sealed chamber. The percentage of carbon dioxide and water vapor of the air inhaled is known, and the amount of respiration is measured by a gasometer. The increase in carbon dioxide and water vapor in the expired air is determined by taking an accurately measured quantity of air from the chamber and passing it through a weighed quantity of sulphuric acid and through potassium hydrate, the one retaining the water, the other the carbon dioxide. From the increase in weight of the sulphuric acid and potassium hydrate, the amount of water and carbon dioxide given off by the person can be calculated.

The inhaled oxygen can be found indirectly as follows: The sum total of the income (food + oxygen) and the body weight at the beginning of the experiment must be equal to the sum of the outgoings and the body weight at the end of the experiment. Hence

Oxygen = (final weight + outgoings) − (initial weight + food).

For this calculation the weight of the urine, fæces, and food, and also that of the body at the beginning and at the end of the experiment, must be determined.

In the respiratory apparatus of Regnault and Reiset, the inhaled oxygen is measured directly. It consists of an air-tight chamber, which is supplied from the outside with pure oxygen only, while the carbon dioxide formed is absorbed by the potassium hydrate. This causes a decrease in the volume of gas in the chamber, and hence new quantities of oxygen are forced into the chamber. The volume of oxygen used is thus determined, while the potassium hydrate holds all the carbon dioxide.

While the calculation of the respiratory metabolism in the above-described methods includes the gas-exchange of the skin, by the method of Geppert and Zuntz the gas-exchange of the lungs only is determined. In this, the experimenter does not breathe in a closed chamber, but, the nose being closed, he breathes through a closed mouthpiece which is connected with the so-called Müller's valves which separate the inspired from the expired air.

By this method also, the oxygen taken up and the carbon dioxide given off is determined directly, for, in measured quantities of inspired and expired air, the oxygen and carbon dioxide are determined by gas analysis. As the amount of air inhaled and exhaled is measured by a gasometer, the total amount of oxygen taken up and of carbon dioxide given off can be calculated.

Occasionally it may be of interest to know the changes in the sulphur, phosphorus, and the salts. The sulphur and phosphorus of the income are changed to sulphuric acid and phosphoric acid by oxidation, and, as such, they are estimated. In the same way the sulphur and phosphorus of the fæces may be determined. In the urine the sulphur and phosphorus are already oxidized to sulphuric acid and phosphoric acid.

The salts of the income and outgo are determined in the ash.

The water is generally accounted for as such in the balance of nutrition.

To be of any value in judging the metabolism of the body, the experiments on metabolism must be carried on for an extended period. Unless otherwise indicated, the results of such experiments are calculated upon a basis of twenty-four hours.

2. THE VALUE OF THE RESULTS OF EXPERIMENTS IN METABOLISM

Determination of the carbon furnishes the basis for studying the history of all the organic foodstuffs in the body. If **carbon equilibrium** is obtained, i.e. if as much carbon is taken up as is given off, as great a quantity of organic substances is consumed in the body as is taken up. If more carbon is taken up than is given off, the body stores up organic substances; but if more is given off than is taken up, the body loses some of its organic constituents.

Determination of the nitrogen affords us information as to the proteids in the body, for all the nitrogen of the income is contained in the proteid. As the proteids contain on the average 16% nitrogen, the amount of nitrogen found, multiplied by 6.25, gives the corresponding amount of proteid. If the amount of proteid decomposed in the body is equivalent to that taken up, the body is in **nitrogenous equilibrium.** If more nitrogen is taken up than is given off, flesh is formed. But if the body gives off more nitrogen than it takes up, it loses some of its proteids.

The proportion of the nitrogen to the carbon in the proteids is as 1 : 3.3. From the estimated nitrogen of the income and outgo, it can be calculated, by means of these figures, how much of the carbon of the income and outgo is derived from proteids. If the amount of carbon derived from the proteid is subtracted from the whole quantity of carbon in the income and outgo, the remainder will indicate the amount of carbon derived from the non-nitrogenous fat and carbohydrates. We can thus determine how much non-nitrogenous foodstuff is consumed in the body and whether the body has increased or decreased in non-nitrogenous substances.

Determination of the inhaled oxygen is of importance in understanding the metabolic processes, for in warm-blooded animals the amount of inhaled oxygen is a measure of the extent of combustion taking place in the body. From the amount of oxygen consumed, it can also be calculated how much hydrogen, besides the carbon, is oxidized in the body.

In cold-blooded animals the estimation of oxygen is of little value, as the oxygen inhaled is not directly used up, but is stored up for a longer or shorter time, because these animals can live for some time in an atmosphere free of oxygen. Warm-blooded animals, on the contrary, do not store up oxygen to any great extent and can therefore endure the lack of oxygen for but a few minutes. An exception to this are the warm-blooded hibernating animals, which appear to be able to store up, during the period of activity, a considerable amount of oxygen.

The **respiratory quotient,** or the proportion between the volumes of the carbon dioxide exhaled and oxygen inhaled, tells us how much of the inhaled oxygen is used to oxidize carbon, forming the carbon dioxide exhaled by the lungs, and how much of it is used in oxidizing other elements, especially hydrogen.

When pure carbon is oxidized to carbon dioxide, the resulting carbon dioxide has the same volume as the oxygen consumed. In such a case the respiratory quotient is **one.** But if, in addition to carbon, hydrogen is also oxidized, then the resulting volume of carbon dioxide is less than the oxygen used up, and the more hydrogen is oxidized, the less is the volume of carbon dioxide. In such a case the respiratory quotient is less than **one.**

The value of the respiratory quotient with carbohydrate combustion is 1; with proteid combustion, 0.8; with fat combustion, 0.7.

Carbohydrates contain sufficient oxygen to oxidize all the hydrogen, hence all the inhaled oxygen is used in the oxidation of the carbon. One litre of oxygen used furnishes 1 litre of carbon dioxide. Proteids and fats do not contain sufficient oxygen to oxidize all their hydrogen. If 1 litre of oxygen is used to oxidize proteids, 800 cc of carbon dioxide are formed; if used to oxidize fats, only 700 cc are formed.

The respiratory quotient can also be greater than one when the amount of carbon dioxide is greater than that of the oxygen taken up. This is the case when, in the body, substances rich in oxygen, e.g. carbohydrates, are reduced to products containing less oxygen, e.g. fats.

The respiratory quotient can also be less than it is during oxidation of pure fat. This occurs when the oxygen introduced is stored up in the form of compounds rich in oxygen.

The respiratory quotient is therefore subject to considerable variations. It is greatest during a carbohydrate diet, smallest during a fat diet. But independently of the diet, the respiratory quotient has been observed to undergo periodic variations, for sometimes relatively more carbon dioxide is given off; at another time relatively more oxygen is taken up. This shows that the oxygen taken up is not immediately used for the formation of carbon dioxide, but first forms compounds rich in oxygen which are, at a later time, completely oxidized to carbon dioxide and water.

Determining the amount of the sulphur and phosphorus in the income and outgo is also of value in studying the proteid metabolism.

The *balance of water* shows not only how much water has been taken up and given off by the body, but also how much water has been formed by combustion processes in the body.

In regard to the substances excreted in the fæces, it must still be mentioned that the fæces contain not only end-products of metabolism, but also undigested and unabsorbed parts of the food. The quantity of the latter substances must be subtracted from the food taken up, for the foodstuffs not absorbed cannot be included in the metabolism. But we have not yet been able to separate the end-products of metabolism present in the fæces from the merely unabsorbed food. The amount of the nitrogen in the end-products of metabolism present in the fæces of an adult man is estimated at one gram per day. This figure is based on observations made upon the fæces during inanition.

3. EXAMPLE OF A BALANCE OF NUTRITION

To illustrate the balance of nutrition we will assume the following case: A man whose body weight at beginning of experiment is 70 kg remains for twenty-four hours in the chamber of Voit's respiratory apparatus. He is fed with meat, bread, butter, potatoes, table-salt, and water. During this time his body weight increases to 70.138 kg.

1. The amount of food taken up is (in grams):

Proteids	130	containing	69 C,	21 N
Fat	100	"	76 "	
Carbohydrates	400	"	176 "	
Salts	30			
Water	2100			
Total income	2760	containing	321 C,	21 N

2. The amount of the outgo in urine, fæces, and respiration is (in grams):

Urine	1355	containing	1280 H_2O,	24 salts,	12 C,	18 N
Fæces	120	"	85 "	6 "	18 "	3 "
Respiration	1867	"	950 "		250 "	
Total outgo	3342	containing	2315 H_2O,	30 salts,	280 C,	21 N

The person has therefore given off 3342 g, while the income is 2760 g. The body weight increased during this time 138 g. Hence some other substance must have been taken in beside the food, and this is the inhaled oxygen.

3. The amount of this oxygen can be calculated from the above data according to the following formula:

$$\begin{aligned}\text{Oxygen} &= (\text{final body weight} + \text{outgoings}) - (\text{initial body weight} + \text{food})\\ &= (70138 + 3342) - (70000 + 2760)\text{g}\\ &= \mathbf{720\ g.}\end{aligned}$$

4. From the foregoing we can strike the following *balance of nutrition* (in grams):

Income (food + oxygen)	3480 containing	321 C,	21 N,	30 salts
Outgo	3342 "	280 "	21 "	30 "
Difference	+138	+41 C		

This table teaches us the following facts:

1. The person was in nitrogenous equilibrium, for the nitrogen of the outgo equals the nitrogen taken in with the proteids of the food.

2. The person was not in carbon equilibrium, for the outgo contains 41 g carbon less than the income. These 41 g carbon have been stored up in the body.

From the figures of the nitrogen it can be calculated that 69 g carbon originated from the ingested and decomposed proteid. Of the 321 g carbon ingested and of the 280 g carbon going out, 69 g originated from the proteid, hence 252 g carbon in the form of non-nitrogenous food has been ingested. Of this, 211 g [280 — 69] was given off, *hence 41 g of carbon in the form of a non-nitrogenous substance is stored up in the body.*

3. Whether this 41 g carbon is stored up in the form of fat or carbohydrate can be determined from the value of the respiratory quotient. The volume of the exhaled carbon dioxide amounts to 464 litres; the volume of the consumed oxygen is 503 litres. This would give us the value of the respiratory quotient:

$$\text{R.Q.} = \frac{\text{vol. } CO_2}{\text{vol. } O_2} = \frac{464}{503} = 0.92.$$

This respiratory quotient is less than one, i.e. some of the oxygen inhaled has been used to oxidize hydrogen. It is, however, much larger than that of proteid, which is to say, that, beside the proteid, but little fat and much carbohydrate has been consumed.

The following may still be said concerning the respiratory quotient. By calculation it will be found that 53 g of the inhaled oxygen have been used up, not in the oxidation of carbon, but in the formation of water. The hydrogen necessary for this has been derived from proteids and fats—not from carbohydrates, for they contain sufficient oxygen to unite with all the hydrogen.

Of the proteids of the food about 116 g have been consumed. From the hydrogen and oxygen found in this quantity must be subtracted, first, the amount found in the urea and, secondly, the amount of hydrogen which can be oxidized by the oxygen present in the proteid. This leaves 3.5 g hydrogen, which need for their oxidation 28 g of the inhaled oxygen.

Of the fat of the food about 90 g have been absorbed. For the oxidation of the hydrogen found in it, 75.5 g of the inhaled oxygen are needed. But of the inhaled oxygen there are remaining only (53 — 28) = 25 g. Hence only 30 g of fat can have been oxidized; the remaining 60 g have been deposited in the body. 60 g fat contain 45 g carbon, which corresponds quite closely with that found in the experiment (41 g).

Hence carbon in the form of fat must have been retained in the body, while the carbon of carbohydrates has been entirely oxidized.

4. There have, then, been deposited in the body 41 g of carbon or about 55 g of fat. But the total increase in body weight was 138 g, hence 83 g more. These 83 g can be present in the body only as water. The balance-sheet of the water shows that 2100 g were taken up and 2315 g given off, hence more water has been given off than taken up. But it must be remembered that in the oxidations taking place in the body, water has been formed. From the oxidized carbohydrates 222 g and from the proteid 48 g and from the fat 30 g of water have been formed, making a total of 300 g. Of this, 215 g [2315—2100] have been excreted, while the remaining 85 g remain in the body. This agrees quite well with the observed figure.

5. The balance-sheet of the salts shows that as much salt has been given off as taken up. Hence the body has neither increased nor decreased in salt.

4. METABOLISM UNDER VARIOUS CONDITIONS

The extent of metabolism is influenced by:

(1) The amount and composition of the food;

(2) The work done and heat lost by the organism;

(3) The size of the body, age, and sex.

I. Influence of food upon metabolism.

A. **Metabolism of the resting body during inanition.**—For a full understanding of the metabolic processes in the body it is of great importance to know the extent of metabolism going on during hunger when the body receives no food or only part of the necessary food. In such a case, the animal maintains the processes of combustion more or less at the expense of its own body substance.

The inanition may either be complete, no food being taken in at all, or partial when only one kind of foodstuff is taken, or when all the necessary kinds are taken but in insufficient quantities.

(*a*) **Absolute inanition.**—Even though no food is taken at all, still the processes of combustion go on, although somewhat reduced. But not all the factors of the total metabolism are equally influenced. The giving off of inorganic constituents, water and salts, steadily decreases during the hunger period. The excretion of sodium chloride soon ceases altogether, while of the other salts, especially potassium and calcium phosphates, small quantities are excreted even up to the time of death, for these salts are rendered unnecessary by the continual breaking down of the tissues. Shortly before death, the amounts of water and salts excreted are increased; this corresponds to the increased breaking down of the tissue immediately prior to death.

The carbon dioxide decreases most during the first stages of starvation; during the latter part it is but slightly decreased. It is difficult to obtain accurate figures as to this, for the extent of the decrease in the carbon dioxide excretion is dependent upon the quantity and nature of food eaten shortly before the beginning of starvation.

The oxygen taken up is also decreased during starvation, but not to such an extent as the carbon dioxide excretion. Hence the decrease in the extent of the combustion during starvation compared with that of a well-fed animal is not as great as the decrease in the formation of the carbon dioxide. During starvation less carbon but more hydrogen is oxidized, so that the oxygen consumption is decreased at most by 20–25%. Hence the respiratory quotient during the first days of fasting is rapidly decreased, but after this remains quite constant till a few days before death. The more body fat there is present, the smaller the value of this constant respiratory quotient. In animals well provided with fat, the respiratory quotient has a value which it ought to have when pure fats are oxidized. A few days before death by starvation the respiratory quotient is increased because of the increased proteid consumption.

The amount of proteid consumed (the nitrogen excretion) decreases very rapidly to less than one-half and then remains constant for a few days till a little while before death, when it becomes larger than it was before starvation. The course of proteid consumption during starvation depends upon the amount of non-nitrogenous material for combustion stored up in the body. Of this material the fats only are of importance, since the carbohydrates (glycogen) are already used up in the first days of starvation. The longer the supply of fat lasts, the longer it takes before the excretion of nitrogen is increased.

That the excretion of nitrogen reaches its minimum during the first days of starvation, that it then remains constant for some time, and at last again increases, is evidently due to the fact that, at first, less proteids are used in the process of combustion than fats, and during the latter part more.

The amount of material lost is not the same for all organs. The organs and tissues suffering most are the adipose tissue, the muscles, and the abdominal glands; the heart, brain, and muscles of respiration suffer less. During inanition the body loses continually in weight, this loss being greatest during the first days. Of this loss, two thirds is due to loss in water, one third to loss in body proteid and fat. The amount of fat lost is from two to four times that of the proteids lost.

The time when death occurs is therefore dependent upon the condition of the body nutrition at the beginning of starvation. Death occurs when a little more than one-half of the body weight has been lost.

Besides the loss of material, starvation causes the following results: The activity of the heart decreases, the number of beats is lessened. General weakness sets in (psychical depression). The body temperature remains the same except just before death, when it falls considerably. The indol and aromatic oxyacids of the urine formed by putrefaction in the intestine disappear, but phenylsulphuric acid is excreted with the urine till death sets in.

(*b*) **Partial inanition.**—If only some constituents of food necessary for life are given, or if all the constituents are given but in insufficient quantities, death by starvation is but delayed.

1. *Lack of water* in the food causes death more speedily than lack of all food. This is evidently due to the fact that, for the normal course of metabolism, a definite proportion must exist between the water and the solid constituents of the body. Besides this, dry food is very soon refused, so that lack of water is finally followed by absolute starvation.

2. *Salt-hunger.*—If no salts are present in the food, the excretion of salts steadily decreases and the excretion of sodium chloride soon ceases altogether even at a time when the body still contains considerable quantities of it. Potassium and calcium phosphates are, however, continually excreted. By eating organic foods the excretion of calcium phosphate is somewhat decreased, because the salt, derived from the breaking down of the tissue, can be utilized in the regeneration of the tissues. Still a part of the salts is continually lost, and since, for the maintenance of life, a certain proportion must exist between the salts and the organic constituents of the body, death finally sets in. Death is preceded by weakness and paralysis.

3. *Lack of all organic constituents in the food.*—If no organic foodstuffs are given, the animal being supplied only with water and salts, death by starvation occurs. The phenomena of metabolism are practically the same as in absolute inanition, the organism consumes its own body

substance. Death, however, occurs a little later than in complete starvation.

4. *Lack of proteids.*—If proteids are excluded from the food, while sufficient water, salts, carbohydrates, and fats are given, the body loses its proteids, and since the fats and carbohydrates cannot shield it against the loss, death by starvation results. The daily loss of proteid is, however, slightly less than in absolute hunger, and hence death occurs somewhat later and without the previous increase in nitrogen excretion.

Notwithstanding the loss of body proteids, the body can lay up fat if the food contains sufficient quantities of fats and carbohydrates.

Even the taking up of gelatin cannot prevent the loss of body proteids. But the loss of body proteid is less if gelatin is eaten than if nothing but fats and carbohydrates are taken. Proteoses, however, are able to replace all the proteids used in the body.

5. *Lack of fats and carbohydrates in the food while sufficient proteids are fed.*—Fats and carbohydrates can be completely replaced by proteids, at least in the carnivorous animals. For example, by feeding upon lean meat, which is nearly a pure proteid diet, a dog can maintain life. But it is not possible to feed man for a long time exclusively with proteid, as he cannot digest the necessary amount of meat.

6. If all the necessary foods are given but in insufficient amounts, two cases are possible. (1) The quantity is absolutely insufficient. The body now continually uses some of its own constituents, hence death by starvation must finally set in, but at a much later time than in absolute starvation. (2) The quantity of food given is only relatively insufficient to maintain the body at the beginning of starvation. In this case, the body loses some of its substance until the amount used and the amount taken are equal. Then the body maintains itself. Hence the body emaciates, but death does not result.

B. **Metabolism during sufficient nutrition.**—The partaking of food increases the metabolism as compared with that during inanition. In this respect the animal body is not like a furnace in which increase of consumption follows increase of supply, for the body can store up a considerable amount of material for combustion. Besides this, the increase in metabolism is less dependent upon the absolute quantity of material furnished than upon the composition of the material.

1. *The effect of proteid upon metabolism.*—The effect of proteid upon metabolism can best be investigated in the carnivorous animals, which can maintain life if merely proteids are given in the food in addition to salts and water. Suppose a dog is fed with as much proteid as it consumes. Its body will be in nitrogenous equilibrium, for the nitrogenous income and outgo are balanced. If to such a dog more proteids are fed, the larger part is used, while only a small part is stored up in the body as flesh.

By this laying up of flesh the demand for proteid is increased, for the demand is proportional to the weight of the body flesh. Nitrogenous equilibrium is again obtained, when the proteids demanded by this newly laid up flesh equal the increase in the quantity of the food proteids. But the possibility of such storing up of flesh is limited, for the digestive organs cannot cope with very large quantities of proteids.

If a dog, maintained in nitrogenous equilibrium by proteids only, receive less proteids, the body loses some of its flesh till the amount of body proteid has reached the point where the demand upon proteid is equal to the proteids supplied in the food; nitrogenous equilibrium is then once more established. At a certain low limit of proteid supply, nitrogenous equilibrium is not regained, for then the body continually uses more proteid than is supplied, and hence death by starvation must result.

The smallest amount of proteid with which an animal living upon a pure proteid diet can maintain nitrogenous equilibrium is considerably more than the amount of proteid decomposed during starvation. If an animal takes up just as much proteid as it decomposes during starvation, nitrogenous equilibrium is not obtained, but the animal decomposes, in addition to the food proteid, some of its body proteid. The more proteid is given in its food, the less body proteid will be used, and when about two and one half times as much proteid is fed as is decomposed during starvation, nitrogenous equilibrium is obtained.

The facts derived from the study of metabolism during pure proteid feeding establish the following laws:

1. Within certain limits the body can maintain nitrogenous equilibrium with any amount of food proteid.

2. Increase in food proteid also increases the consumption of proteids.

This increase in proteid consumption has been regarded as "Luxus-consumption," but it is not without beneficial effect, for by it the power of the body is increased.

2. *Effect of fats and carbohydrates on metabolism.*—If a person fed on a mixed diet (proteid, fats, carbohydrates, water, and salts) and brought to a condition of nutritive equilibrium is supplied with an increased amount of non-nitrogenous foods (fats and carbohydrates), the amount of non-nitrogenous material consumed in the body is increased, but the consumption of proteids is decreased to an extent expressed by the law of isodynamics (see page 117). Hence, in reality, no general increase of combustion in the body will take place. Fats and carbohydrates therefore shield the proteids, and the proteid is stored up in the body as flesh. If there is still more fat or carbohydrate present in the food, these are stored up in the body, chiefly in the form of fat.

As far as their influence upon the extent of metabolism is concerned, there is no real difference between fats and carbohydrates, but the carbohydrates are more easily oxidized and shield the proteids better than fats. In general, they can replace each other according to the law of isodynamics.

Gelatin also shields proteids, and even more so than carbohydrates.

If, in the above assumed case where nutritive equilibrium is maintained with a mixed diet, the amount of fat, carbohydrate, or gelatin is increased while the amount of proteid remains constant, the proteid saving is slight. In such cases, the gelatin may shield 30% of the proteids, the carbohydrates 15%, and the fats still less. But the shielding of proteids is much more effective when, simultaneously with an increase in the other foodstuffs, the amount of proteids is decreased. When the proteid of the food is replaced by fat, carbohydrates, or gelatin, a much smaller quantity of proteid is able to keep the body proteid constant than if the diet consists chiefly of proteids. The minimum amount of proteid in a mixed diet, i.e. the absolutely necessary proteid (see page 117), is for a man about 70 g daily; but it has been observed that for a short time he can maintain his body proteid with 40 g of food proteids. But with such small quantities of proteids more fat and carbohydrates must be supplied than would strictly follow from the law of isodynamics. The foodstuffs which can shield the proteids differ from each other in this capacity; the gelatin shields proteids best, then the carbohydrates, and, least of all, the fats. In regard to fats it must be added that the eating of very great quantities may increase the consumption of proteids.

If, in a sufficient, mixed diet, the proteids are increased, the following results:

1. The extra proteid is, as in pure proteid diet, in part deposited in the body, and part used up. Hence in a mixed diet also, an increase in the supply of proteid causes an increase in proteid consumption.

2. But by this increase in proteid consumption the oxidation of fats and carbohydrates is somewhat lessened, so that fat may be deposited.

3. In this case also, fats and carbohydrates spare the proteids to such an extent that a greater part of the proteid

is deposited and a smaller part oxidized than occurs in an exclusive proteid diet.

From what has thus far been said, it follows that the various foodstuffs are not of the same value for the organism. In general, the body has the tendency to be less sparing with the proteids than with the fats and carbohydrates.

It also appears that the body can maintain its equilibrium by foodstuffs mixed in various proportions. The question is, which is the most suitable mixture? The most suitable, or the **rational diet** for an adult man, is 100 g proteid, 60 g fat, 400 g carbohydrates. These figures have been obtained by various experiments in metabolism in men. From the experiments it has been observed that the figures do not differ to any large extent with the occupation and place of dwelling of the subject experimented upon.

If the 60 g of fat are changed, according to the law of isodynamics, into carbohydrates, the proportion of proteids and carbohydrates in the daily meal is as 1 : 5.5.

If, in feeding, the object is not only to keep the body weight constant but to increase either the flesh or the fat in the body, more foodstuffs must be taken in. But to increase either the body flesh or fat, it is not a matter of indifference which foodstuff is increased.

The **laying up of flesh** can only be produced by proteid food; for from fat and carbohydrates no flesh can be formed. But, by increasing the proteids of a diet predominating in proteids, little flesh is laid up. For the laying up of flesh the most suitable diet is a moderate amount of proteids besides large quantities of fats and carbohydrates. But if considerable flesh is to be laid up, other conditions than the nature of the food play an important part. For example, the laying up of flesh (muscles) is especially favored by proper muscular exercise (training).

Fattening of the body.—The fat laid up by the body originates from:

(*a*) The fat in the food; for if a fat containing specific constituents (rape-seed containing erucic acid) normally not found in the body is added to the food, we find this fat deposited in the body.

(*b*) The carbohydrates of the food from which by reduction and synthesis fat is formed. By a diet rich in carbohydrates glycogen and fat are deposited in the body. Consequently the respiratory quotient may be greater than one; i.e. carbohydrates must have been reduced and changed to fats in the body. By this process oxygen would be set free, which could then be utilized, in connection with the inhaled oxygen, in the formation of carbon dioxide.

(*c*) It has been supposed that fats can be formed from proteids, but no sufficient proofs have been furnished.

For the purpose of laying up fat the best diet consists of a moderate amount of proteid and an abundant supply of fat and carbohydrate.

3. *The effect of water and salts.*—Increase of water taken up does not change the amount of metabolism, but during the first day the excretion of nitrogen is increased, due to a better washing away of the nitrogenous end-products of metabolism.

Neither does increase in sodium chloride produce any changes in the extent of metabolism.

4. *Effects of spices.*—Alcohol does not change the metabolism. Alcohol, like the other non-nitrogenous foodstuffs, is completely oxidized soon after being taken into the body and can therefore replace fats and carbohydrates. But, as alcohol is a strong nerve poison, it cannot be regarded as a valuable material for metabolism.

Concerning the effects of spices upon metabolism, authors differ widely.

5. *Effects of oxygen.*—Voluntary increase or decrease in the amount of respiration has no effect upon metabolism, for the taking up of oxygen and the giving off of carbon dioxide is not altered by increased or decreased ventilation during a few minutes. The increased activity of the muscles of respiration may, of course, influence metabolism. Diminution in the amount of hæmoglobin in the blood, by loss of

half the blood, produces no change in the extent of metabolism, for the lack of oxygen is completely covered by increased respiration and heart activity, so that oxyhæmoglobin is used to better advantage than normally. But if real lack of oxygen occurs, e.g. in dyspnœa or excessive muscle work, the metabolism does not decrease, but, on the contrary, there is an increase in the decomposition of proteids. But the combustion is, in this case, incomplete; hence considerable quantities of lactic acid are excreted with the urine (see page 42).

Increase or decrease in atmospheric pressure has, within certain wide limits, no effect on the amount of combustion in the body.

II. **The effect of work and loss of animal heat upon metabolism.**

(*a*) **Effect of muscular activity.**—By muscular work the respiratory metabolism and all the processes of combustion are increased. The combustion process may be increased four or five times the normal amount. During moderate work the respiratory quotient is the same as during rest. But during excessive work the increase in the excretion of carbon dioxide may be greater than that of the oxygen taken up, so that the respiratory quotient is increased.

The consumption of proteids is generally not increased by work, hence the increase in combustion must be at the expense of non-nitrogenous substances, fat, or carbohydrates. Often, however, the excretion of nitrogen is also increased by muscular activity; this is always the case in exclusive or predominating proteid diet. But if sufficient fats or carbohydrates are present in the mixed diet, there is no increase in nitrogenous excretions. During muscular activity, the body generally consumes non-nitrogenous material. But if the work is very excessive, an increase in the excretion of nitrogen may result even with a mixed diet containing much fat and carbohydrate. This is perhaps due to the fact that excessive work injures the muscle tissue. To maintain the body at its weight during work it must be supplied with more food than during rest. For work the rational diet is, proteids 130 g, fat 100 g, carbohydrate 500 g. In this diet the proteids are also increased because a man doing hard work has a better developed muscular system and therefore a greater demand for proteids than a resting or slightly active persor. Hence the proper diet of a working man serves not only to replace material consumed but, as the power of work is proportional to the amount of muscle, to increase the amount of flesh.

(*b*) **Effect of the work of digestion.**—In considering the activity of the body, the material and energy used in the processes of digestion and absorption must not be omitted. Under digestive work we include the activity of the glands, the movements of the alimentary canal, and the activity which the epithelial cells of the intestine exhibit in taking up material from the intestine and transferring it to the blood or lymph. But it is impossible at present to say how much of the increased metabolism observed after the taking up of food is due to this increased activity and how much is due to the increased supply of material for combustion. It is nevertheless beyond doubt that the digestive work causes a considerable increase in metabolism, and it has even been asserted that the difference between the metabolism of a fasting and that of a fed organism is entirely due to this increase in the activity of the alimentary canal. But it is supposed that the energy for this activity is not supplied by fats or carbohydrates but by proteids, for during digestion the nitrogenous excretion in the urine is greatest; hence more proteids are consumed at this time.

(*c*) **Effect of loss of body heat.**—The human body maintains its own temperature independently of the external temperature. This body temperature is maintained at its proper height by continual combustion (see Chapter XIII). The body continuously loses heat which must be replaced by the combustion of new food material. The amount of heat given off depends upon the external temperature; the lower this is, the more heat is lost by the body and the more oxidation must take place in order to maintain the body temperature. Hence the extent of metabolism increases with lowering of the external temperature and decreases when the external temperature increases. This change in metabolism affects chiefly the combusion of fats and carbohydrates. The increase in metabolism during loss of heat is caused by a reflex increase in combustion in the muscles which produces muscle contraction (shivering).

The power of the human body to adjust itself to great variations in external temperature is limited. If the external temperature is very low, the loss of heat may become greater than the heat production and the body temperature falls. The lower the body temperature falls, the more slowly the vital processes take place and the less heat is produced until, at last, the processes of combustion cease altogether and the organism freezes to death. If the external temperature is so high that the body produces more heat than it can give off, the body temperature rises. This causes an increase in the vital processes and more heat is produced until, at last, the body is overheated and death results. In the increased metabolism the consumption of proteids is also increased.

Within the limits in which the body can accommodate itself, a fall in external temperature increases metabolism, and a rise decreases it. But, outside of these limits, the effects are exactly the reverse, for a decrease in external temperature causes a fall, and an increase, a rise in the body temperature. Hence, in the last-mentioned case, man is like the cold-blooded animals, in which the metabolism rises and falls with the external temperature.

But it will be shown that, for the regulation of the body temperature, besides the mechanism for regulating the metabolism, another and far better mechanism regulating the loss of heat is present (see page 181).

(*d*) **Effect of sensory stimulation and psychical activity.**—Stimulation of the skin and strong stimulation of the retina by light increase the consumption of oxygen and production of carbon dioxide. Hence during sleep the respiratory exchange of gases is considerably decreased. Besides, during sleep the muscular movements, except those of the heart and respiratory muscles, are reduced to a minimum, and the muscle tonus also, which maintains the position of the body, is inhibited. The proteid metabolism is not affected by sleep.

It has not yet been definitely proven that psychical activity has any effect upon metabolism.

III. **Effect of the size of the body, age, and sex upon metabolism.**—Small persons have a relatively greater metabolism than large persons, for, since in them the surface by which heat is lost is larger in proportion to the heat-producing mass than in large individuals, the smaller person must produce relatively more heat in order to keep a constant body temperature than the larger person. Hence the metabolism of a child is relatively greater, although absolutely smaller than that of the adult (see page 118). In old age the metabolism is smaller than in the prime of life. Because of differences in the size of body, the metabolism in a woman is less than in a man, therefore the diet for woman is also less. An adult, resting woman needs 90 g proteids, 40 g fat, and 350 g carbohydrate daily. During pregnancy the metabolism is increased. Sex itself has no influence upon metabolism.

PART II

THE TRANSFORMATION AND SETTING FREE OF ENERGY

The potential chemical energy of the body substance is changed to kinetic energy (heat and muscular activity) by the physiological combustion.

The cause of the transformation of energy lies partly in the living substance itself, partly in the stimulations which act upon the living substance. The stimulations either have their origin in the body itself and serve to regulate the relation existing between the individual organs, or they originate in the external world and serve by their stimulating effect to connect the body with its environment. To receive these external stimulations, the body is provided with special organs, the sense organs. The stimulation is carried from the sense organs by means of a special apparatus, the nervous system, to the muscles in which the transformation of energy chiefly takes place.

The study of the transformation and setting free of energy may be divided into the following chapters:

1. Animal heat.
2. Muscular contraction.
3. Functions of the nervous system.
4. Functions of the sense organs.

CHAPTER XIII

ANIMAL HEAT

1. **Heat production.**—In the animal body the heat formed originates from the potential chemical energy of the food. In a resting body, in which no energy is used up for external work, as much heat is formed as corresponds to the potential chemical energy set free during combustion. Hence the law of conservation of energy holds good also for the transformation of energy in the living body.

Heat can also be imparted to the body by the taking up of food and drink warmer than the body, but this is of little importance and does not occur regularly.

In the working body the energy transformed is equal to the heat produced and the external work done.

The work of the heart, of the muscles of the alimentary canal, and of the respiratory apparatus is not reckoned with the external work, for their work is transformed into heat in the body.

The unit of heat is the *calorie.* A calorie is the amount of heat needed to raise 1 kg of water from 0° to 1° C.

The unit of work is the *kilogrammeter*, which is the work done by raising 1 kg the distance of 1 meter. One calorie equals 425 kilogrammeters.

The chemical energy of an oxidizable substance is indicated by its heat of combustion, i.e. the heat set free by the complete oxidation of the substance. The following table gives the heat of combustion of a few substances:

Hydrogen..............	34.0	calories.
Carbon.................	8.0	"
Fat......................	9.3	"
Sugar..................	3.7	"
Starch..................	4.5	"
Proteid................	5.5	"

Proteids are not completely oxidized in the body, for the urea formed from it can still undergo oxidation. If the heat value of urea is subtracted from that of proteid, there remain for one gram of proteid 4.1 calories.

The physiological heat values are:

For 1 g proteid 4.1 cal.; 1 g fat 9.3 cal.; 1 g carbohydrate 4.1 cal.

As far as their heat production for the organism is concerned, the following substances are isodynamic: 2.3 g proteid (or gelatin) = 1 g fat = 2.3 carbohydrate.

If the extent of metabolism is known, we can calculate from the heat value of the substances oxidized the amount of heat formed. Conversely, by finding the amount of heat produced we can calculate the extent of metabolism; but this calculation is not conclusive as to the individual kinds of foodstuffs used.

The production of heat is measured by the water- or air-calorimeter. In the water-calorimeter the body is placed in a tin case which is surrounded by a layer of water. The heat given off by the animal heats this water. The respiratory air is supplied through tubes of which the one carrying the exhaled air passes through the layer of water which surrounds the case, so that the heat of the exhaled air is imparted to the water also. From the increase in temperature of the water, the amount of heat lost by the body can be calculated. This amount equals the heat formed, for the body temperature is the same at the end as at the beginning of the experiment. In the air-calorimeter the tin case is surrounded by a layer of air whose expansion by the heat measures the amount of heat set free.

The adult resting human being produces in twenty-four hours about 2400 calories, or in one hour 100 calories. This is 34 calories per kilogram of body weight in twenty-four hours, and 1.4 cal. in one hour.

The amount of heat produced is dependent upon the same circumstances as metabolism. Muscle activity increases heat production, for, of the extra energy set free thereby, only a part can be used in the performance of work, the rest being changed to heat. Of all the energy set free by a working body, at most only one-fourth can be utilized for mechanical work; the remaining three-fourths is set free as heat. During hard work an adult man produces in twenty-four hours, for every kilogram of body weight, an amount of heat, including the external work, equal to 55 calories.

2. **The loss of heat.**—The body continuously loses heat:

(1) By radiation and conduction from the surface of the body to the surrounding air, which, as a rule, is colder than the body.

(2) By the evaporation of water from the skin, especially by the secretion of sweat. By this means the body can lose heat when the surrounding medium has a higher temperature than the body itself.

(3) By exhaling air which has been heated to the body temperature and is saturated with water vapor. The water vapor is imparted to the expired air by the evaporation of water from the mucous membranes of the air passages.

(4) By heating up the ingested food and drink; in other words, by voiding excretions heated to the body temperature (urine, fæces).

Of all the heat lost by the body, about 80% is lost by radiation, conduction, and evaporation from the skin; about 15% by evaporation from the mucous lining of the air passages; one half of the rest by expired air, and the other half by the excretions.

The amount of heat which is lost in each of these ways is variable. The lower the external temperature, the more heat is lost by conduction from the skin and by heating the inhaled air; the loss of heat by evaporation is greater, the drier the air and the greater the amount of sweat secreted. The heat lost by expired air depends upon the frequency and depth of respiration.

3. **Body temperature.** — Man belongs to the warm-blooded or homoiothermic animals whose body temperature is, apart from very slight variations, constant. The body temperature of man is 36.5–37.5° C.

The body temperature is measured by placing a thermometer in the rectum, vagina, mouth, or axilla, the arm being placed in the proper position around the thermometer.

The blood streams from the tissues where most of the heat is produced (muscles and large glands) to the skin, where it becomes cooled. The temperature of the muscles is therefore somewhat higher, and that of the skin lower, than that of the blood.

The body temperature shows some regular minor variations; shortly after midnight it is lowest (36.5°), while in the afternoon it is highest (37.5°). It is somewhat increased by the partaking of food and by muscle activity.

Mammals have about the same body temperature as man; in birds it is higher (40–45°). The body temperature of cold-blooded or poikilothermic animals is a few degrees (1–4°) higher than that of the surrounding medium (provided they have not been placed in a warmer or colder medium just previous to the measurement).

Hibernating mammals are, during their winter sleep, like cold-blooded animals.

4. **Regulation of body temperature.**—The body temperature remains constant when the production of heat equals the loss of heat. If changes occur in the production of heat (e.g. by muscular activity) or in the loss of heat (e.g. in hot or cold weather), the production and loss of heat must again be regulated in order to keep the body temperature constant. Concerning the nature of the regulation of temperature by the nervous system little is known.

Some authors think that there are in the central nervous system certain centres (heat centres) by which the mechanism for regulation of body temperature is governed. But the account given of these centres and their mode of action is not satisfactory.

By the regulation of temperature both the production and the loss of heat can be varied.

Changes in the production of heat occur when the loss of body heat is altered by variations in the temperature of the surrounding medium. In cold weather the production of heat is increased to such an extent that involuntary muscular contraction takes place (chattering of teeth, shivering).

In small animals the proportion of the surface by which heat can be lost to the heat-producing body mass is greater than in larger animals. Therefore, in order to maintain a constant body temperature smaller animals must produce more heat per kilogram of body weight than larger animals. The adult human being produces, at rest, per kilo-hour 1.4 calories, while a child four years old produces about 2.5 calories, a rabbit 5.6 calories.

If the loss of heat is stated in terms of the unit of body surface, it is found that it is about the same in animals of various sizes. The amount of heat lost by man per square meter is about 1200 calories in 24 hours.

Variations in the loss of heat take place because of:

(1) Increased or decreased supply of blood to the skin, whereby the heat carried to the cooling body surface is increased or decreased. The supply of blood to the skin is increased by the dilation of the cutaneous vessels and the increase of pulse rate; it is decreased by the contraction of the vessels and the decrease of the pulse rate.

(2) Secretion of sweat, which, by evaporation, cools the body.

(3) Increase or decrease in the frequency or depth of the respirations, whereby more or less heat is given off by the expired air.

Muscular activity, by which more heat is produced, or raising of the external temperature (warm weather) are followed by perspiration, increased pulse and respiration, and dilation of the cutaneous vessels; lowering of the external temperature (cold weather) causes constriction of the cutaneous vessels.

We can voluntarily regulate the loss of heat by warming ourselves, by clothing, by the position of the body, and by partaking of cold or warm drinks. We can regulate the production of heat by voluntary muscular activity. In animals hairs and feathers serve to regulate the loss of heat.

Our ability to keep the body temperature constant by means of the heat-regulating mechanism is, however, limited. This regulation of temperature fails when the temperature of the surrounding medium is too high or too low, so that changes in the production or loss of heat are no longer able to prevent the body temperature from rising or falling. Very strong cooling also disturbs the regulation of temperature by paralyzing the muscles of the blood vessels so that the cutaneous vessels become dilated to an abnormal extent. When the temperature regulation fails, the body temperature speedily sinks below 19° or rises about 42° and death results.

In fever, the regulation of temperature is disturbed; the production of heat is increased, hence the body temperature is abnormally high.

Within certain limits, the heat production in cold-blooded animals is the larger, the higher the temperature of the external medium, for, in these animals, the intensity of the combustion taking place in the body increases with the raising of the external temperature.

CHAPTER XIV

GENERAL MUSCLE PHYSIOLOGY

THE active movements of the body are produced by the contraction of the muscles whose fibres shorten in their longitudinal direction (contraction). They perform work by the movement of the parts connected with them (bones).

The physiology of the movement may be divided into:

(1) General muscle physiology, the study of general properties of muscles.

(2) Special muscle physiology, which treats of the actions of individual muscles.

Anatomical considerations.—The striated muscle is composed of muscle fibres, varying in length up to 12 cm and having a diameter of 0.01–0.06 mm. These fibres are surrounded and held together by connective tissue (perimysium internum and externum). In this connective tissue are found nerves and blood vessels. The muscle fibre is composed of a bundle of parallel fibrils, between which there is a protoplasmic substance, the sarcoplasm. The fibre is surrounded by a structureless covering, the sarcolemma. Directly beneath the sarcolemma lie the muscle corpuscles, spindle-shaped and nucleated protoplasmic bodies.

The smooth muscle is composed of fibre-like cells without any sheath. The cells vary in length and diameter up to 0.5 mm and 0.02 mm respectively and contain rod-like nuclei. Sometimes fibrils and sarcoplasma are found in smooth muscles.

The fibrils which seem to contain the contractile part are, in the smooth muscle, composed throughout their entire length of doubly refracting parts (anisotropic), while the striated muscle fibril is composed of alternate doubly and singly refracting (isotropic) parts. The striated appearance of muscles is caused by the alternate arrangement of parts which vary in transparency.

In the middle of each isotropic (light) disk there is, in the striated muscle, a narrow dark band called the *intermediate disk*, or membrane of Krause, on both sides of which there is another dark band called the *secondary disk*. In the centre of the anisotropic (dark) disk there is a narrow light band, called the *median disk of Hensen.* The physiological importance of these structures is still unknown.

By double refraction exhibited by many crystals a single ray of light is broken up into two rays. The double refractive muscle substance has an optical axis in the longitudinal direction of the fibres, in which the light is broken but once. The importance of this doubly refracting substance of the muscle fibrils for the property of contractility is not known.

The motor-nerve fibres are connected with the muscle fibres, the axis cylinder of the nerve fibre forming a flat arborization (end-plate) which lies in contact with the muscle fibres.

Nearly all the striated muscles can be voluntarily stimulated, except the heart muscle. The stimulation of most of the smooth muscles is not subject to our will, except the muscle of accommodation of the eye.

The contraction of the muscle takes place when it is stimulated. In a stimulated muscle the physiological combustion is increased, whereby energy is set free which produces the contraction and performs the work. The manner in which the potential chemical energy is transformed into mechanical work is still unknown.

I. THE RESTING MUSCLE

1. Chemical properties of a resting muscle.

(*a*) *Composition of muscles.*—The reaction of a resting muscle is neutral or feebly alkaline. A muscle contains 25% solids, which include:

1. Proteids 20%.

If a fresh frozen muscle is cut up and the extract filtered at about 3°, a cloudy neutral or feebly alkaline fluid is obtained. This is the fluid contents of the fibres or the **muscle plasma.** At higher temperatures it coagulates spontaneously and, the higher the temperature, the more speedily it clots. The coagulation is due to the formation of an insoluble proteid, **myosin,** from a soluble proteid of the muscle plasma, myosinogen, by the action of the ferment. Coagulation also occurs during rigor mortis. The myosin forms about 20% of the muscle proteids.

The solution which is left after myosin has been formed is called the **muscle serum.** It has an acid reaction and contains about

80% muscle albumin. The remainder is chiefly composed of a proteid, called myogen.

The muscle also contains an undissolved proteid of unknown nature, collagen, and the nuclein-like phosphocarnic acid which, by splitting up, yields phosphoric acid, a sugar-like product, lactic acid, and carnic acid, a substance belonging to the peptones.

In addition to the above-named proteids, the muscles contain a pigment, myohæmatin, which is identical with the hæmoglobin of the blood; but it is not derived from hæmoglobin, for animals without blood also have this pigment in their muscles.

2. Carbohydrates, chiefly glycogen, stored up between the muscle fibrils; grape-sugar in small and varying amounts; inosit.

3. Fats, chiefly deposited in the intramuscular connective tissue. The amount varies with nutrition.

4. End-products of metabolism, chiefly keratin and xanthin bases; also sarcolactic acid.

5. Salts, especially potassium phosphate.

Muscles contain carbon dioxide, but no free oxygen can be obtained from them.

(*b*) *Chemical processes in the resting muscle.* — The physiological combustion in the resting muscle manifests itself by the consumption of oxygen and the production of carbon dioxide. This is evident from the fact that arterial blood is changed to venous blood in the muscles.

2. **Mechanical properties of a resting muscle.**—The muscle is elastic and, in the longitudinal direction of its fibres, extensible. During this extension, the length of the muscle increases, its thickness decreases; its volume undergoes no change.

The elongation during extension is not proportional to the weight which causes the extension, for the extension produced by one and the same weight is the less, the more the muscle is already stretched. Hence the curve of extension, i.e. the curve whose abscissa represents the weight and whose ordinate represents the length of the muscle, is not a straight line, but a hyperbola (see page 192).

2. THE STIMULATED OR ACTIVE MUSCLE

1. **Chemical processes in the active muscle.**—In the active muscle the processes of combustion are enormously increased. During muscular activity the consumption of oxygen and the formation of carbon dioxide may be increased to four or five times that during rest. During this activity more carbohydrates or fats are used, while the consumption of proteid remains the same, if sufficient fat and carbohydrate are present. But if these are not present in sufficient quantities, the muscular activity takes place at the expense of proteid. This is evident from the metabolism of the body during rest and work. The taking up of oxygen and the giving off of carbon dioxide are always enormously increased by muscular activity, but the nitrogenous excretions are only increased when the food does not contain sufficient non-nitrogenous substances to supply the energy for the work, e.g. during purely proteid diet.

The respiratory quotient is not changed by muscular activity, if the work is not extreme; but if the work is fatiguing, it is increased.

The amount of glycogen in the muscles and in the liver is decreased by work. Body fat may also be lost by work.

The active muscle has an acid reaction. Sarcolactic acid of the muscle is increased by activity.

Although no trace of free oxygen is present in the muscles of a frog, still an excised frog-muscle placed in an atmosphere free of oxygen can do work. They therefore contain oxygen stored up in the form of chemical compounds which can be used when necessary.

Muscles of warm-blooded animals contain, at best, only a small supply of stored-up oxygen, for they lose their irritability soon after the supply of arterial blood is cut off.

The amount of substances capable of extraction with water is decreased by activity, while those extracted by alcohol are increased. It is said that the amount of phosphocarnic acid [phosphorfleischsäure] in the muscles is decreased by activity.

2. **The external phenomena during the transformation of energy in an active muscle.**—The transformation of energy reveals itself in definite mechanical, thermal, and electrical changes in the muscles.

A. Mechanical changes in the stimulated muscle.

(*a*) **Contraction.**—The stimulated muscle shortens in its longitudinal direction, the diameter increases, while the volume remains the same.

Both the anisotropic and the isotropic bands of the striated muscle change in the same sense as the whole muscle. That the volume of the anisotropic part is increased, while that of the isotropic part is slightly decreased, is explained by the passing of water from the isotropic to the anistropic part. Besides this, the optical difference between the two parts becomes less.

Twitching.—If a muscle is acted upon by a stimulus lasting for but a short time (by an induced electric current), it draws itself together rapidly and then again immediately lengthens. This is called a twitch.

The length of time consumed by a twitch is investigated by the graphic method. The muscle is connected with a writing-lever which is moved by its contraction and writes its movement on a travelling surface. Such an apparatus for the graphical registration of a muscle contraction is called a myograph.

An *isotonic contraction* is a contraction during which the tension (tonus) of the muscle remains constant. The isotonic contraction curve shows the duration of the contraction during constant tension. To obtain such a curve a writing-lever must be used which is thrown upward as little as possible by the contracting muscle. A light lever is used and a weight is hung as near the axis as possible, while the muscle is attached to the lever at considerable distance from the axis. During normal physiological conditions, a muscle does not contract isotonically, but always with change in tension.

An *isometric contraction* is a contraction in which the shortening of the muscle is completely prevented, so that tension is produced without the shortening of the muscle. The changes in tension in an isometric contraction can be registered by the so-called tension recorder.

A noticeable length of time elapses between the moment of stimulation and the beginning of contraction; this time is called the latent period. The contraction occurs at first with increasing and then with decreasing rapidity till the maximum is reached; after this the muscle relaxes, at first rapidly, but soon more slowly until it has acquired its former length. Frequently the relaxation is not complete, especially when the load of the muscle is small (see Fig. 9).

The length of the latent period for the skeletal frog-muscle is, at room temperature, about 0.01 second, for human muscle 0.004 to 0.01 second, for smooth muscle 0.4 to 0.8 second.

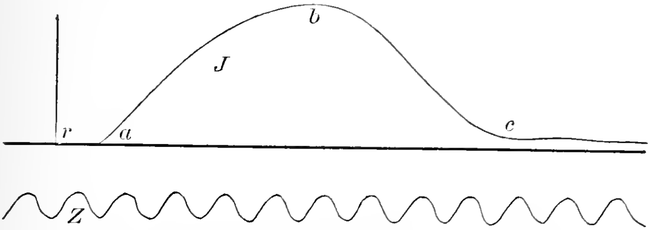


FIG. 9.—ISOTONIC CONTRACTION OF A FROG-MUSCLE.

J, curve of contraction; *r*, moment of stimulation; from *r* to *a*, latent period; from *a* to *b*, period of increasing energy; from *b* to *c*, period of decreasing energy; *Z*, time-curve produced by a vibrating tuning fork (each vibration equals 0.01 second).

The duration of contraction for a skeletal muscle of a frog at room temperature is about 0.1 to 0.15 second, for a human muscle a little less, for a smooth muscle 1 to 3 minutes. Various striated muscles of the same animal contract with different rapidity, e.g. the gastrocnemius of a frog contracts more rapidly than the hyoglossus. Many animals (rabbits, birds) have slowly contracting striated muscles which have a red color and are poor in sarcoplasm, while they also have rapidly contracting muscles which are white and contain much sarcoplasm.

The extent of the contraction (height of contraction) in a maximal contraction of a frog-muscle is about one-fifth of the length of the fibre.

Conditions influencing the contraction.

1. *Temperature.*—Between the temperature of − 40° and + 40° C. the duration of the contraction and the latent

period are the shorter the higher the temperature. The height of the contraction also changes with the temperature, but it is not increased merely with the raising of temperature, for a cold muscle may give greater contraction than a warm muscle.

2. *The load.*—In general, the height of the contraction is less the greater the load of the muscle. But it must be observed that the height of contraction of a muscle without any load is slightly less than that of a moderately loaded muscle.

3. *Fatigue.*—If a muscle has made many successive contractions, the duration of the contraction and latent time increases; the height of the contractions at first slightly increases, but later on gradually decreases.

Concerning the influence of the strength of the stimulus upon contraction see page 197.

Wave of contraction.—Though but a limited portion of a muscle is stimulated, the whole muscle contracts. The contraction is propagated in the form of a wave in both directions from the spot stimulated throughout the muscle fibres. If the motor nerve of a muscle is stimulated, the wave of contraction spreads from the place of entrance of the nerve through the fibres.

The rapidity of the contraction wave is measured by stimulating a certain part of the muscle and placing two recording levers at unequal distances from the stimulated spot. The increase in diameter of the muscle due to contraction will not meet the two levers at the same time, and this difference in time will represent the length of time taken by the contraction wave to travel through the distance which separates the two levers.

The rate of the contraction wave in the skeletal muscle of a frog at room temperature is three metres per second, for the muscles of a rabbit four to five metres, and for a human muscle ten to fifteen metres. In smooth muscles it is ten to fifteen mm per second. The rate is decreased by cooling the muscle and by fatigue. The duration of the contraction wave in the cross-section of a fibre is of course less than the duration of contraction of the whole muscle; it is about 0.05 to 0.09 second in the frog-muscle. The length of the contraction wave in the frog-muscle is 200–380 mm.

In striated muscles, except in the cardiac muscle, the contraction does not pass from one fibre to another as it does in the smooth muscles.

Superposition of twitches. Tetanus.—If a muscle is stimulated by many single stimuli which follow each other so fast that the interval between two successive stimulations is less than the duration of the contraction, the individual twitches called forth by the individual stimulations combine. But the increase in contraction which each successive stimulation produces is smaller than that of the preceding. Finally a maximum contraction is reached which cannot be surpassed by the succeeding stimulations. If the interval between the stimulations is small enough, a lasting contraction is produced by the combination of the twitches, which is called tetanus. In a frog-muscle tetanus is produced at room temperature when about 20 stimulations per second are sent into the muscle.

In a muscle without any load, the height of a tetanic contraction may be 80% of the length of the fibre. In a loaded muscle it is less in proportion as the load is greater.

It is difficult to tetanize the cardiac muscle (see page 64).

The voluntary muscle contraction is also tetanic. This is apparent from the variations frequently seen in the contraction of a voluntarily contracted muscle which can be graphically registered by recording the thickening of the muscle. There are about 8 to 12 oscillations in one second.

Muscle-sound.—If an artificially stimulated muscle is connected with the ear by means of a sound-conductor, a sound is heard which corresponds to the number of oscillations. From voluntarily contracted muscles a sound is also heard (19 vibrations per second), but it is doubtful whether this sound is produced by the oscillatory stimulation of the muscle during voluntary contraction, for a sound is also heard during a single twitch (see first cardiac sound, page 68).

Extensibility of the tetanized muscle.—The tetanized muscle is more extensible than the resting muscle. The curve of its extensibility resembles a hyperbola, but its course is steeper than that of a resting muscle (Fig. 10).

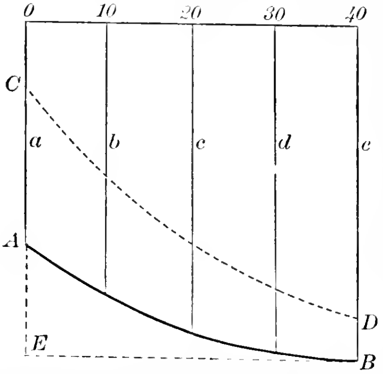


Fig. 10.—Curves of Extensibility of a Resting and an Active Muscle (Diagrammatic).

a, b, c, d, e. are the length of a resting muscle loaded with 0, 10, 20, 30, 40 grams; the curve *AB* which joins the ends of these perpendiculars represents the curve of extensibility. Correspondingly, *CD* represents the curve of extensibility of the tetanized muscle.

Continuous contraction not tetanic.—By the action of continuous stimuli upon muscles (e.g. stimulation by ammonia, a constant current) a continuous contraction is produced, of which it has not been proven that it is produced by the combination of twitches.

(*b*) **Work done by a stimulated muscle.**—The work done is the product of the weight raised by the height to which it is raised. Other things being equal, the height of the contraction is proportional to the length of the fibres.

The force with which the weight is raised is, other things being equal, proportional to the cross-section of the muscle. In muscles in which the fibres run obliquely, the so-called physiological cross-section, that is, the cross-section of all the fibres, must be taken into consideration.

The *absolute force* of the muscle is equivalent to the weight which just prevents the contraction of a maximal tetanized muscle. The absolute force of the striated frog-muscle is 3 kg for 1 sq. cm. of cross-section, of the human muscle it is 10 kg.

The work done by an active muscle is zero if the load is zero or if the load is so great that the muscle can no longer raise it. Between these two extremes the amount of work done increases with the increasing load up to a certain maximum, beyond which it decreases.

The raising of the load to a height equal to the extent of the contraction of the muscle is not the greatest amount of work capable of being performed by the muscle. The muscle does more work when

(1) The load is not raised, but is thrown upward; it can then rise higher than the corresponding contraction of the muscle.

(2) When the contracting muscle after it has raised the load is gradually unloaded. Then the muscle shortens more and performs new work by raising the lessened load. Many muscles in the human body, because of the relation of their joints, work according to this advantageous principle of unloading.

In addition to the performing of real work, the muscles also perform the function of keeping raised weights suspended and of holding the individual parts of the body together. This also takes place with expenditure of energy by the tension of the muscles.

An adult man can perform, in eight hours, a work of about 300,000 kilogrammetres.

B. **The formation of heat by active muscles.**—Of the energy set free by an active muscle at most only one-fourth is used for the performance of work, the remainder being transformed into heat.

The muscles work much more economically than the steam-engine, for, in the best-constructed steam-engine, only one-tenth of the energy set free by the burning of the coal is used in doing work.

When no external work is done, all the transformed force appears as heat; in this case we can calculate the extent of metabolism by measuring the heat produced in the stimulated muscle. When a tetanized muscle, carrying a load, holds the load suspended, it no longer does any work, hence all the transformed energy appears as heat.

To conduct the experiment in such a manner that the muscle in acting shall do no external work, the raised weight is left on the muscle, and when the muscle relaxes it is allowed to sink. The heat produced by an excised frog-muscle is measured by the thermo-electric method, a delicate thermopile being used. In many cases the heat produced by a contracting muscle can be directly measured by a delicate thermometer placed upon the skin over the muscle.

By a single contraction the frog-muscle increases in temperature by 0.001° to 0.005° C., during tetanus more. The amount of heat produced by the twitching of a frog-muscle of one gram is about three micro-calories. This amount of heat is produced by the oxidation of 0.0008 mg sugar.

C. **Electrical phenomena in the active muscle.**—The part of the muscle in contraction is negative to the resting part. The development of electricity during contraction occurs mostly during the latent period, so that the negative phase is nearly past before the contraction begins. The wave of contraction is preceded by a "negative wave."

Suppose *AB* in Fig. 11 to be a muscle fibre, the points *a* and *b* of which are connected with a galvanometer *L*. If we stimulate the muscle at *C*, immediately after the stimulation has reached *a* an electric current passes through *L* from *b* to *a*, *a* having become negative. Soon after this, when the stimulation has reached *b*, the current passes through *L* from *a* to *b*. These currents are called the action-currents and follow each other with great rapidity.

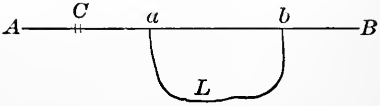


FIG. 11.

They are investigated with the same apparatus as the action-currents of nerves (see page 217).

Secondary contraction, secondary tetanus.—If the nerve of a muscle-nerve preparation is placed upon the surface of another muscle, and if the latter or its nerve be stimulated, both muscles are thrown into simple contraction or tetanus. The action-current of the stimulated muscle passes over into the nerve of the other muscle-nerve preparation and stimulates it. Lasting contractions, not of a tetanic nature, do not produce secondary tetanus.

If a muscle is cut across and one of the electrodes of a galvanometer is connected with the transverse section, while the other electrode is connected with the longitudinal surface, a current passes through the galvanometer from the longitudinal to the cut surface. This is called the **current of rest.** At the cut surface the muscle dies and this is connected with processes which render the dying part negative to the part intact. If now the longitudinal surface is stimulated, the intensity of the current of rest is decreased; this is called the **negative variation.**

The electromotor force of the current of rest of a muscle is about 0.07 volt.

The cause and the significance of these electrical phenomena in stimulated and dying muscles is not well understood.

3. THE STIMULATION AND THE IRRITABILITY OF THE MUSCLE

The stimulations which call forth the activity of the muscle may be divided into:

A. *Indirect,* i.e. stimulations which act upon the motor nerves and thus upon the muscle. In this class belong the normal physiological stimulations which are carried from the central nervous system through the motor nerves to the muscles.

B. *Direct,* i.e. stimulations which affect the muscles directly. The muscle is directly irritable without the intervention of the nerves, as is proven by the following facts:

(*a*) In the sartorius muscle of a frog the nerve fibres distribute themselves only in the middle of the muscle, for the two ends, as proven by microscopic examination, are free of nerve fibres for about one-eighth of the total length of the muscle. Yet stimulation of the ends, free of nerve fibres, produces contraction of the muscle.

(*b*) Ammonia stimulates the muscles directly, but does not stimulate the nerve fibres.

(*c*) Curare paralyzes the nerve endings in the muscle. In an animal poisoned with curare, stimulation of the nerve has no effect upon the muscle, yet the curarized muscle is directly irritable.

(*d*) "Idiomuscular" contraction is the local contraction of the muscle fibres produced by the mechanical stimulation of an abnormal muscle (fatigue, disease). This contraction is produced only at the place of stimulation, the contraction not being spread along the nerve fibres.

The direct stimuli of the muscles are:

1. *Mechanical.* Cutting and pinching of the muscle stimulate it.

The external mechanical conditions also have an influence on the irritability. With stimuli of the same strength, the greater the resistance which the contraction of the muscle encounters, the more energy is set free. This is useful, for the muscle offers more force against greater resistance.

2. *Thermal.* Heating above 40° produces a continuous contraction which finally goes over into heat rigor identical with rigor mortis (see page 198). Below the temperature of 40°, the irritability increases with the temperature.

3. *Chemical.* Certain chemical agents stimulate the muscle, e.g. ammonia, alkaline sodium salt solutions; but these speedily injure it so that it becomes non-irritable. Other substances, such as acids, merely injure the muscle without previously stimulating it. Physiological salt solution (0.6% NaCl) is indifferent.

4. *Electrical.* A constant current of sufficient strength passing through a muscle in its longitudinal direction causes contraction when the current is made, and sometimes also when the current is broken. During the passage of the current through the muscle, the muscle undergoes a lasting contraction, which is, however, less marked than the initial or make contraction.

If the current is passed transversely through the muscle, it does not stimulate it.

By studying the nature of the wave of contraction, it has been found that in the make contraction the stimulation begins at the negative pole (kathode) and from there spreads throughout the muscle, while in the break contraction it begins at the anode.

Induction currents stimulate only at the kathode.

In order to stimulate, the current must be active for a certain length of time; currents lasting for a very short time are not effective. The different kinds of muscles behave differently in this respect. While striated muscles are more affected by sudden changes in the intensity than by long duration of the current, in case of smooth muscles it is the reverse.

At the places of entrance and exit the current changes the irritability of the muscle in the same manner as in the nerve (see page 220).

The electromotor resistance of the muscle in the longitudinal direction is two and one-half million, that in the transverse direction is twelve and one-half million, times greater than that of mercury.

Relation between the stimulation and the contraction.—The extent of the contraction (measured by the heat produced) increases with the strength of stimulation up to the higher limit, beyond which increase in the stimulation does not produce an increase in contraction.

The **irritability** of the muscle is dependent upon the normal vital processes, as well as upon the previously mentioned influences (mechanical conditions, temperature, chemical agents, electrical currents).

Excised muscles of warm-blooded animals lose their irritability in a few hours; those of cold-blooded animals, at a moderate temperature, in two to three days, while in a lower temperature they retain their irritability for a long time (as long as twelve days). Stoppage of circulation or lack of oxygen soon destroys the irritability of muscles of warm-blooded animals.

Irritability is maintained only by the proper alternate succession of rest and activity. On the one hand, the irritability is lost by complete rest (e.g. in limbs which remain at rest for a long time in fixed bandages); on the other hand, the irritability is decreased by too great stimulation. Section of the motor nerve after some time also destroys the irritability of the muscles and causes it to degenerate.

Fatigue manifests itself by decrease in irritability and ability to do work; subjectively it manifests itself by painful sensations in the muscle. The fatigue is due to:

(1) Decomposition products (e.g. sarcolactic acid) produced by the prolonged activity of the muscle which decrease the irritability.

(2) The disappearance of material for furnishing energy.

If the fatigued muscle is allowed to rest, it recovers and the irritability increases by the removal of the fatigue-substance and by a fresh supply of oxidizable material.

Rigor mortis.—During the death of a muscle phenomena similar to those of a contracting muscle appear, namely, contraction (produced by the tension of the muscle in rigor mortis), production of heat, consumption of oxygen, formation of carbon dioxide and lactic acid, disappearance of glycogen, electrical phenomena. Rigor mortis has therefore been regarded as the last contraction of the dying muscle.

Besides the above-named processes, the coagulation of myosinogen also takes place; this causes the dead muscle to have a whitish, cloudy appearance.

The nervous system influences rigor mortis. Rigor mortis sets in later in a muscle whose motor nerve has been cut than in a muscle whose nerve has not been cut.

Heat rigor, which takes place when a muscle is killed by heating it above 40° C., is identical with rigor mortis.

Physiological differences between smooth and striated muscles.—The smooth muscles differ physiologically from the striated in the following points:

1. The striated, except the cardiac muscles, are voluntary muscles; the smooth, except the ciliary muscles of the eye which function during accommodation, are involuntary.

2. The smooth muscles contract more slowly and the contraction wave is much longer than in the striated muscles (see page 190). Of the striated muscles,the cardiac muscle contracts more slowly than the skeletal muscles. But in the cardiac muscle the striation is less perfect than in skeletal muscles. The more nearly perfect the cross-striation the greater the velocity of contraction.

3. Smooth muscles are more readily stimulated by long duration than by sudden changes in the intensity of the electric current, while the striated muscles are more readily stimulated by sudden changes in the intensity of the current.

4. In the smooth muscle the stimulation passes from one fibre-cell to another, not so in the striated muscle (except cardiac).

Protoplasmic and ciliary movement.

1. *Protoplasmic movement.*—White blood corpuscles, like amœba, change their shape by the thrusting out and drawing in of pseudopods. By attaching a pseudopod to the underlying surface and drawing the body along by the contraction of the protoplasm, they are also able to move from place to place. During rest the pseudopods are withdrawn and the cell is spherical.

Within the limits of temperatures by which the cell is not injured, the higher the temperature the greater the protoplasmic movements. At a temperature of a little above 40° C. the pseudopods are withdrawn; in heat rigor the cell is spherical. Lack of oxygen paralyzes.

If the cells are stimulated by an induction current, the pseudopods are withdrawn. Stimulations which work upon the cell from one side, e.g. chemical influences, may have an orientating effect upon the movements of the cell. The wandering of the leucocytes through the walls of the blood vessels into the tissues seems to be caused by chemical stimulation falling upon the cell from one side only.

The constant electric current also orientates the movements of naked protoplasmic bodies, by polarization at the places of entrance and exit. In many amœbæ the movements are always towards the kathode. The orientating effects of chemical and electric stimulations are called chematropism and galvanotropism.

2. *Ciliary movements.* — The epithelial cells of many mucous membranes have, on their free surfaces, cilia which move forward and backward in a definite direction. The movement in one direction takes place with greater velocity than in the opposite direction, hence light particles resting on the surface of the mucous membrane are carried forward in that direction in which the movement is stronger.

The ciliated epithelial cells of a mucous membrane stand in close physiological relation to each other, so that the movements of all the cilia occur in a definite, orderly manner. The nature of this physiological relationship is not known.

The activity of the cilia is favored by oxygen and by the feeble alkalinity of the surrounding fluid.

In man, cilia are found in the mucous membrane of the air passages, uterus, oviducts, and on the ependyma of the cerebral ventricles. The movements of the cilia in the air passages force the mucous and the inhaled dust outward; the movements of the cilia in the oviducts and uterus serve to move the egg forward.

The *spermatozoa* are composed of a head and a long thread-like tail. This tail, by making whiplike or pendulatory movements (analogous to the cilia of the ciliated cells), propels the spermatozoa forward. These movements are increased by the feeble alkalinity of the medium in which the spermatozoa move; they are decreased by acid fluids.

CHAPTER XV

SPECIAL PHYSIOLOGY OF THE MUSCLES

THE subjects of the special physiology of the muscles are:

1. The functions of the skeletal muscles in general.
2. Standing, walking, and running.
3. The voice.

1. FUNCTIONS OF THE SKELETAL MUSCLES IN GENERAL

A. **The bones and their articulations.**—The bones are rigid bodies which support the various soft parts of the animal body. They are formed so as to furnish the greatest strength with the least bulk. To accomplish this the long bones are hollow, and in the short bones the lamellæ are especially closely packed in the direction in which the greatest pressure or pull is exerted (see Fig. 12).

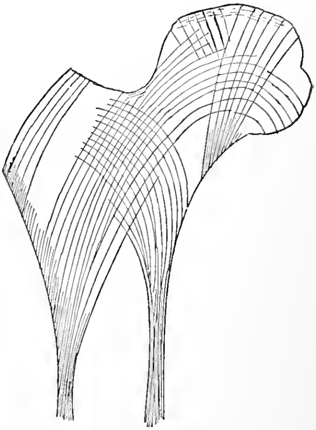


FIG. 12.—UPPER PART OF THE FEMUR, SHOWING THE ARRANGEMENT OF THE LAMELLÆ. (After H. Meyer.) The lamellæ are especially closely packed in the direction in which the weight of the body acts and in which the muscles inserted upon the trochanter major act.

The articulations may be divided into:

1. **Synchondrosis,** the articulation of two bones by means of cartilage. In synchondrosis, the bones retain, when no external forces are active, a definite position towards each other; when external forces are applied, the bones can move upon each other in all directions, the cartilage being twisted. Such movement is, however, very limited.

2. **Joints,** i.e. articulation without definite position of equilibrium of the articulated bones.

The two surfaces by which the two bones are jointed touch each other; they are smooth and can move over each other, and this movement is aided by the synovia, a fluid found in the joints which acts as a lubricant.

Synovia is an alkaline stringy fluid which is rendered cloudy by the remains of cells. It contains proteids, salts, and a nucleo-albumin which is similar to but not identical with mucin. Its composition varies with rest and activity.

Frequently there is found between the two bones of the joint a cartilage which serves to give greater surface to the joint and aids in the movement of the bones in cases where the two heads of the bones do not fit into each other.

The joints are covered by the capsular membrane. This is a connective tissue membrane fastened to the bones which, by its flaccidity, allows the movements of the bones against each other.

Many joints, amphiartrosis, have a membrane so tense that no movement of the bones is possible. These joints are, from a mechanical standpoint, equivalent to the synchondroses.

The surfaces of the joint are *planes of rotation*. A plane of rotation is a plane described by a curve when it is rotated around a straight line lying in the plane of the curve.

The joints are classified according to the form of the curve describing the plane of rotation and the position of the axis of rotation.

1. The curve is the arc of a circle.

(*a*) The straight line passes through the centre of the circle. The plane of rotation is a part of a spherical surface. A joint with such planes is called a ball-and-socket joint, or arthrodia. In such a joint the jointed bones turn around any number of axes of rotation which all pass through the centre of the sphere. We may, however, conceive of all the possible movements as movements around three lines perpendicular to each other and passing through the centre of the sphere. Examples: hip-joint, shoulder-joint.

(*b*) The straight line does not pass through the centre of the circle.

(*α*) It lies on the concave side of the arc: oval plane, *oval joint.*

The oval joint has two axes, of which one coincides with the rotation axis of the plane of rotation; the other, passing through the centre of the arc, is perpendicular to the first axis. Example: radio-carpal joint.

(*β*) The straight line lies on the convex side of the arc: *saddle-joint.*

The saddle-joint has two axes which are analogous to those of the oval joint. Example: joint between the trapezium and the metacarpus pollicis.

2. The curve has any form except that of a circle, and the straight line may have any position.

Such joints are called *hinge-joints;* they have one axis of rotation which coincides with the axis of the plane of rotation. If one of the two bones forming a hinge-joint is imagined to be fixed, a given point of the second bone, on moving, describes a circle. Example: joints of the phalanges.

As special cases we must also mention:

1. The *screwed-surface joint,* a joint with one axis and in which a given point of the supposed movable bone describes a spiral line instead of a circle. In the screwed-surface joint the bones, during turning, slide over each other in opposite directions but move in the direction of the axis. Example: the elbow.

2. The *spiral joint.* The plane of rotation of the spiral joint may be conceived of as follows: The curve which by its rotation describes the plane of rotation approaches during this movement nearer to the straight line. A given point in the curve, therefore, does not describe a circle but a spiral. Hence a given point of the imaginary movable bone describes not a circle but a spiral. Example: the knee.

Mechanisms by which the joints are held together.—Besides the ligaments (ligamenta accessoria of the hinge-joint) and the tension of the surrounding muscles, the bones of the joints are held together by atmospheric pressure.

If, in a dead body, all the connections between the femur and the pelvis are cut, and also the capsular membrane of the hip-joint, the femur still remains in its socket because atmospheric pressure presses the surfaces of the joint against each other. The force with which the bones are held together by atmospheric pressure is, in the hip-joint, about 22 kg, which is more than the weight of the limb.

Limitations in the movements of bones connected by joints.—The movements of the bones are naturally limited, often especially so by processes of the bone (e.g. the olecranon process, which prevents the complete rotation of the elbow forward) and by ligaments (e.g. the posterior crucial ligament of the knee, which prevents the complete backward bend of the knee).

B. **Action of the muscles upon the bones.**—By the contraction of a muscle its points of insertion are brought nearer together. Hence a muscle can only act when its points of insertion can approach each other.

But the *line in which the insertion points approach each other* does not always coincide with the longitudinal direction of the muscle fibres, because the insertion points are not free to approach each other in a straight line, but the nature of their movement is determined by the nature of the articulation.

If, for example, the two insertion points are attached to two bones articulated by ball-and-socket joint, and if we imagine one bone as immovable, then the insertion point on the other bone can only assume points all of which lie in a spherical plane. If the bones are articulated by a hinge-joint, the insertion joint on the imaginary movable bone can move only in a circle.

By the contraction the insertion points approach each other because the muscle fibres are stretched straight between the insertion points.

If the muscle fibres are not stretched straight between the insertion points but move over a pulley-like arrangement, the points of insertion can, by the contraction of the muscle, go farther apart. This is the case, e.g., in the superior oblique muscle, whose insertion on the eyeball is removed by the contraction of the muscle from its insertion in the optic foramen, because the trochlea serves as a pulley.

All the force of a contracting muscle is effective for mechanical work only when the insertion points move in the longitudinal direction of the fibres. In all other cases only a part of the muscle force is effective. This part is found by resolving the force into its components according to the law of the parallelogram of forces.

EXAMPLE.—In Fig. 13, let AB and AC be two bones which by the hinge-joint A move around a line passing through A perpendicular to the plane of the paper. J and J_1 are the insertion points of a muscle fibre m, by the contraction of which the point J_1 is moved forward in the direction perpendicular to AC (J is supposed to be immovable). If the force of the muscle is represented by the length of the line J_1D, that part of the force which causes J_1 to move forward is found by resolving J_1D into its components. According to the law of the parallelogram of forces, draw J_1E and its perpendicular J_1F. J_1E indicates the amount of force which causes J_1 to move forward.

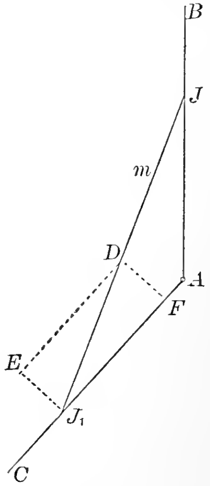


FIG. 13.

If, in a hinge-joint, the direction of pull of a muscle acting upon a given point of the movable bone does not fall in the plane of the circle described by the moving point, the muscle force must be resolved into three components. One of these, the active component, falls in the direction of the moving point, the other two, inactive, are perpendicular to this and also to each other, and one of these lies in the plane of the circle.

In a ball-and-socket joint the muscle force is resolved into two components whose directions fall in the plane of traction of the muscles and the centre of the ball. One of these components, the active, lies in the direction in which the supposed movable insertion point moves in this plane; the other is perpendicular to this.

If two or more muscles work upon a movable bone, we first determine the active component of each force, and of these individual active components we find the single resultant according to the law of the parallelogram of forces.

Muscles acting in the same direction are said to be synergetic, while antagonistic muscles are those which act upon a joint in opposite directions.

We may analyze the movements of the bones according to the laws of the lever, for all movable bones may be considered as one- or two-armed levers. The length of the lever-arms from force to fulcrum and that from fulcrum to weight is the distance from the axis of the joint to the point at which the force and the weight work.

In the body, the lever-arm of the force is generally smaller than that of the weight. This is not unfavorable, however, for by it we gain velocity, even though it be at the expense of force.

During the motion of the supposed movable bone, the amount of the effective force frequently changes because of changes in the lever-arm either of the force or of the weight.

Of interest is the decrease of the weight-arm during the movement, for thereby the muscle works more advantageously (see page 193). An example of a movement of the body during the unloading [Entlastung] of a muscle is the elevating of the body by the knee-joint. In the position with flexed knee, the lever-arm of the weight is the horizontal distance of the axis of the knee-joint from the perpendicular line through the centre of gravity of the body, which lies at the promontorium. This distance becomes smaller as the body is elevated and, in the upright position, is zero. The direction of pull of the quadriceps, which straightens the knee, retains, during the movement, approximately the same distance from the axis of the knee-joint.

2. STANDING, WALKING, RUNNING

The general erect position (standing) and the general modes of locomotion (walking, running) have a typical form in all people, for they are based upon a common principle, that of the least muscular exertion. We are accustomed so to stand and move that the muscles are as little exerted as possible.

In **standing erect** the position of the body is such that the centre of gravity is vertically over the base formed by the feet, and when the limbs are placed against each other, the longitudinal axis of the body is nearly vertical.

The base of support is a hexagon whose angles are formed by the heads of the first and fifth metatarsus and by the calcaneum on both sides. The centre of gravity of the body lies somewhat in front of the promontorium of the spinal column.

The muscles which during quiet standing fix the limb are, in reality, only:

1. Calf-muscles. The contraction of these prevents the body from falling forward which might be caused by the bending of the lower part of the leg at the ankle-joint.
2. The muscles of the neck, by the contraction of which the forward sinking of the head is prevented (lowering of the chin upon the chest as in sleep).
3. To a smaller degree the neck and hip muscles, which prevent the bending of the cervical and lumbar vertebræ.

Besides this the limbs are held firm by the following ligaments:

(1) The superior ileo-femoral ligaments (ligamenta Bertini) which prevent the body from falling backward by turning at the hip-joints.

(2) The posterior crucial ligaments of the knee-joints, which prevent the body and the upper part of the legs from falling forward by turning at the knee-joints.

As the arms hang loosely suspended by the sides of the body, they need no mechanism for fixation.

Many authors suppose that the body is not thrown forward but backward by the bending of the knees. If this is true, the fixation of the knees is not caused by the posterior crucial ligaments, but by the quadriceps femoris.

Turning the feet out aids in holding the lower limb against the foot in the ankle, for in placing the feet outward the two axes of the joints do not fall in the same direction but converge forward. This makes a simultaneous rotation around both axes, without a change in the position of the legs, impossible.

Locomotion.—In locomotion, the head, the trunk, and the suspended arms must be regarded as a body balanced upon the legs at the hip-joints. The legs support the body and, by stretching, push it forward. The leg can swing forward and backward without any muscular exertion. In order that the one leg may swing forward, it is somewhat elevated by a slight bending at the hip-, knee-, and ankle-joints; the body is meanwhile supported by the other leg.

The top part of the body is slightly bent forward during locomotion; this is the greater the faster the motion. *The forward movement of the body is produced by the alternate action of one leg supporting the body and pushing it forward while the other, slightly bent, swings forward.*

In **walking,** a period during which both feet are on the ground is followed by a period in which only one is placed on the ground while the other swings. In **running,** a period during which neither foot rests on the ground is followed by a period during which one stands while the other swings.

The process from the beginning of the swinging of one leg until the beginning of the swinging of the other is called a step. The velocity of locomotion is the greater the longer the step and the greater the number taken in a given time (or the smaller the duration of the step). The velocity of locomotion during walking is limited—maximum 2.5 m per second—because, on account of the simultaneous resting of both feet on the ground, the length and number of the steps cannot exceed a certain amount. In running, the velocity of motion can be greater than in walking because the length and number of steps can be increased, on account of the simultaneous swinging of both feet.

In walking, the velocity is the greater the lower the position of the head of the femur. Synchronously with the movements of the legs, a rhythmical pendulation of the arms takes place, in opposite direction to that of the legs.

The alternate rising and sinking of the body during walking is small (about 32 mm).

The work done by the body during walking on a horizontal plane is about 3 kilogrammetres for each step; during running it is more. This work is, however, not lasting, since, during each step, the elevation of the body is lost.

3. VOICE AND SPEECH

1. **Production of voice.**—The larynx with the vocal cords forms a reed organ with membranous reeds. During the production of voice the inner borders of the vocal cords approach each other and are stretched. When, now, the expired air passes through the larynx, the vocal cords vibrate. By this vibration of the cords, the glottis alternately opens and closes so that the expired air is emitted intermittently. In this manner, vibrations of the air are produced which are strengthened by the resonance of the pharynx and mouth and can be perceived as sounds by the ear.

(*a*) *The mechanism of the vocal chords.*—The cartilages concerned in the study of the vocal cords are:

The *cricoid*, a cartilaginous ring at the upper part of the tracheal wall; it has the form of a signet ring with the broad part on the posterior side (*cr*, Fig. 14).

2. The *thyroid* (*th*) consists of two perpendicular plates which meet at a right angle in front; the posterior border is continued upward as the large horn, and downward as the small horn (*a*). The points of the small horns form joints with the sides of the cricoid. The axis of this joint around which the thyroid turns is horizontal from right to left.

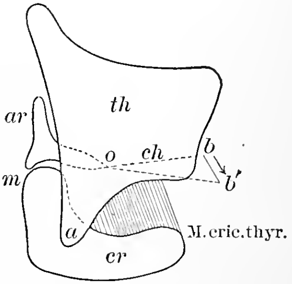


FIG. 14.—PROFILE OF THE LARYNX.

th, thyroid cartilage; *a*, smaller horn of the thyroid cartilage; *ar*, arytenoid; *m*, processus muscularis; *r*, processus vocalis; *ch*, vocal chords; *cr*, cricoid; *b–b′*, direction of movement of the thyroid cartilage during contraction of the cricothyroid (*M. cric. thyr.*).

3. The *arytenoids* (*ar*) are two three-sided pyramids

whose bases are movably articulated with the posterior parts of the upper surface of the cricoid.

The vocal cords are foldlike processes of the inner wall of the larynx, which in front are attached to the posterior wall of the thyroid; at the rear they are attached to the vocal processes, which are anterior processes of the triangular bases of the arytenoids. During quiet breathing the space between the vocal cords and the two arytenoids, called the glottis, is open. The glottis has the form of an isosceles triangle (Fig. 16, I). When the glottis, for production of voice, must be narrowed, the arytenoids approach each other until they come into contact and the vocal cords are tense.

A. In the closing of the glottis, the following parts function:

1. The *transverse and oblique arytenoid muscles*, which are inserted on the posterior side of the two arytenoids and by their contraction draw the posterior parts of the arytenoids toward the median line (Figs. 15 and 16, II and III).

2. The *lateral crico-arytenoid* on both sides, which proceeds from the lateral surface of the cricoid upward and backward to the muscular processes (lateral angle of the base of the arytenoids). By the contraction of the muscles the arytenoids are turned about a vertical axis and the vocal processes are drawn toward the median line. Its antagonist is the *posterior crico-arytenoid*, which alone turns the vocal processes outward and, in conjunction with the lateral, turns the whole arytenoid outward. In this manner the glottis is opened.

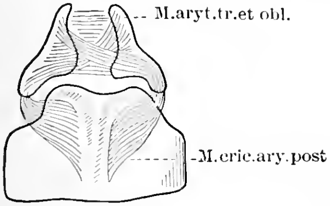


Fig. 15.—Posterior View of Larynx.

M. aryt. tr. et obl., transverse and oblique arytenoid muscles; *M. cric. ary. post.*, posterior crico-arytenoid muscle.

B. To render the vocal cords tense, the following parts function:

1. The *crico-thyroid muscle*, which pulls the thyroid

forward and a little downward and hence increases the tension of the vocal cords attached to the thyroid.

2. The *thyro-arytenoid muscle*, imbedded in the vocal cords, function as the antagonist of the last-named muscle. If it contracts simultaneously with the crico-thyroid muscle, both it and the vocal cords which are formed by it are rendered tense. Its contraction also aids in the closing of the glottis, for the slightly outward-bent borders of the vocal cords are stretched by its contraction.

Innervation: The crico-thyroid is innervated by the superior laryngeal nerve; all the others by the inferior laryngeal.

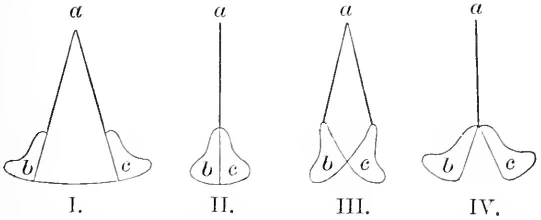


FIG. 16.—REPRESENTATION OF THE POSITION OF THE VOCAL CORDS (DIAGRAMMATIC).

a, anterior end of the vocal cord; *b* and *c*, base of the arytenoid cartilages; I, position of rest; II, the arytenoid have approached each other and the vocal cords are in position for voice formation; III, form of the glottis during contraction of the transverse and oblique arytenoid muscles and the posterior crico-arytenoid; IV, form of the glottis during contraction of the lateral crico-arytenoid muscles.

(*b*) *The pitch, range, and quality* (*timbre*) *of the human voice.*—The pitch of a reed pipe depends on the number of vibrations of the reed. In a membranous reed, it depends upon the length, thickness, and tension of the reed, hence the pitch of the human voice is the higher the less the length and thickness and the greater the tension of the vibrating parts of the vocal cords.

Individual variations in the pitch of the voice are determined by the length and thickness of the vocal cords. The vocal cords of a man, for example, are thicker and longer (18 mm long) than those of a woman (12 mm long), hence the man has a deeper voice than the woman.

Children do not show this difference in voice. The change of the voice in man takes place at puberty. Castration prevents this change.

One and the same individual produces tones of various pitch by:

(1) Changes in the tension of the vocal cords, produced by:

(*a*) Changes in the contraction of the muscles which cause the tension of the cords to vary.

(*b*) By changes in the force with which expired air is emitted.

If the air is exhaled forcibly, the vocal cords are brought into a new and slightly raised position which produces a greater tension than when they are stretched straight between their points of insertion.

The force of the exhaled air is generally 13–17 mm Hg.

(2) Variations in the length and breadth of the vibrating parts of the vocal cords.

(*a*) Variation in the length of the vibrating part is produced by the greater or less pressing together of the arytenoids. If these are loosely pressed together, the edges of the arytenoids also vibrate, but if they are firmly held, the vocal cords only vibrate. In the first case the vibrating reed is longer than in the second case.

(*b*) By peculiarities in the contraction of the thyro-arytenoid muscle or by the so-called false vocal cords being placed upon the true vocal cords so that only the small inner margins of the true cords are allowed to vibrate. Because of the small extent of the vibrating part, the pitch is high. It is used in the so-called falsetto.

(3) Variations in the thickness of the vocal cords.

Fibres of the thyro-arytenoid muscle, having a perpendicular direction, by their contraction cause the upper and lower surfaces of the vocal cords to approach each other and thus change their thickness.

The **range** of the voice includes all the tones which an individual can produce; generally it embraces two octaves.

The range of the voice varies in different individuals. We may classify them as:

Base, ranges from E to f'.
Tenor, ranges from c to c''.
Alto, ranges from f to f''.
Soprano, ranges from c' to c'''.

The **timbre** of the voice depends upon the number and strength of the overtones which accompany the fundamental tone produced in the larynx. It is also dependent upon accompanying noises. In one and the same individual we can distinguish, by means of the timbre, the chest-tone from the falsetto. The resonance of the chest-tone is chiefly produced in the thorax and is deeper; the resonance of the falsetto is chiefly produced in the mouth, pharynx, and nose, and is higher. The resonance only affects the timbre and strength, not the pitch, of the voice.

The difference between the voice during singing and speaking is not fully understood.

2. **Speech.**—The sounds of speech are produced by expiration, which causes noises to be produced in the mouth or nose and in the pharynx. These sounds may or may not be accompanied by the voice.

Vowels are sounds of speech accompanied by the voice. The tones which, produced in the buccal and pharyngeal cavities, accompany the voice to give to it the vowel character, are called the *determinants* [Formanten] of the vowels.

Each vowel has one or two characteristic determinants which are independent of the pitch of the voice. These are, according to Helmholtz: for *oo* as in *food*, f; for *o* as in *no*, b'; for *a* as in *father*, b''; for *a* as in *ate*, f' or b'''; for *e* as in *scheme*, f and d''''. Other authors give other determinants.

In the several vowels the determinants are different because of the difference in the position of the buccal and pharyngeal cavities. For the production of *a* as in *father*, the cavity of mouth and pharynx has the shape of a funnel with the apex toward the pharynx; for the production of *o* as in *no*, and *oo* as in *food*, it has the form of a flask with a short neck; while for the production of *a* as in *ate*, and *e* as in *scheme*, it has the form of a flask with a long neck.

Perhaps there are, in the formation of vowels, besides these definite determinants, others which are produced by the resonance of the buccal and pharyngeal cavities, the pitch of which depends upon the pitch of the voice, just as the pitch of an overtone depends upon the fundamental tone.

Consonants are sounds not accompanied by the voice. They are classified as:

1. Resonants; *m*, *n*, *ng*; produced by closing the mouth and driving the air through the nose.

2. Explosives; *b*, *p*, *d*, *t*, *g*, *k*; produced by the formation of an obstruction to the expired air, or the removal of such an obstruction (the nasal passage being closed).

3. Aspirates; *w*, *f*, *s*, *l*, *sh*, *z*, *zh*, *th*, *j*, *ch*; produced by driving the expired air through a constricted portion of the mouth.

4. Vibratories; *r*; produced by the exhaled air throwing the walls of a constricted portion of the buccal cavity into vibration.

According to the position of the obstruction or constriction in the buccal cavity we can distinguish between labials, dentals, and gutturals.

The sound of *h* is formed when the exhaled air is unobstructedly driven through the mouth while the nasal passage is closed.

CHAPTER XVI

GENERAL NERVE PHYSIOLOGY

1. THE CONSTRUCTION AND FUNCTION OF THE NERVE ELEMENTS

THE nervous system is composed of nerve units called **neurons.** The neuron is made up of:

(1) A *nerve cell*, and (2) its *processes*, which may be divided into:

(*a*) *Protoplasmic processes* or dendrites, which are short, much-branching processes, rapidly decreasing in size.

(*b*) *An axis-cylinder process* or neurite, which differs from the dendrites in its hyaline, smooth appearance. Its thickness is uniform throughout its course. At the end it splits up into a group of brushes, the so-called end-tufts. Many axis-cylinders give off lateral branches (collaterals) which also end in tufts. The axis-cylinder, the most important part of each nerve fibre, is sometimes longitudinally striated owing to the fibrils of which it is composed. Between the fibrils is found the neuroplasma, a finely granular substance.

The physiological processes in this nerve unit are such that when the cell is stimulated either automatically (without any outside stimulation) or by some outside stimulation, which is taken up by the protoplasmic processes and carried to the cell. The stimulation is also taken up by the axis-cylinder which conducts it to the end-tufts. Thence it is communicated to the organ with which the end-tufts are connected (cells of other nerve elements, muscle fibres, or gland cells.

The protoplasmic processes carry the stimulation cellulipetally, i.e. to their cells; the axis-cylinders carry it cellulifugally, or from their cells. Accordingly, the peripheral sensory nerves which carry the stimuli cellulipetally must be regarded not as axis-cylinder processes but as elongated protoplasmic processes.

The process of irritability and conductivity of the individual neuron is the elementary physiological process which lies at the basis of the functions of the nervous system.

The transmission of the stimulation from one neuron to another is perhaps accomplished by delicate nerve fibrillæ which connect the end-tufts of one neuron with the protoplasmic processes of another neuron. But it is difficult to demonstrate such fibrillæ anatomically.

Neuroglia and medullary sheaths appear to be supporting and protecting organs for the real nerve-substance.

General nerve physiology is divided into two parts, corresponding to the two parts of the neuron.

1. General physiology of the nerve fibres,—including the sensory nerves which must really be regarded as dendrites.

2. General physiology of the nerve cells.

2. GENERAL PHYSIOLOGY OF THE NERVE FIBRES

1. **The irritability and conductivity of nerves.**—The nerve fibres serve to carry impulses from one end-organ, the receiving organ (sense organ or nerve cell), to the other end-organ (muscle, gland cell, or other nerve cell). The stimulation of a nerve takes place normally in the receiving organ, but can also be applied to any part of the nerve by artificial stimulation.

The nature of the impulse and of the conduction of the stimulation is not known. The only token of the impulse which has been observed is an electrical phenomenon. An active part of a nerve is negative to the resting part. The significance of this phenomenon is not known.

In Fig. 17 let *AB* be a nerve; at *a* and *b* place the electrodes of a galvanometer (*L*), and stimulate the nerve at *C* by means of an induction current. Shortly after stimulation the impulse reaches *a*, and an electric current passes from *b* to *a* through *L*. When the impulse has passed *a* and is carried to *b*, a current passes from *a* to *b* through *L*. These currents are called **action currents.** Their rapidity is so great and they follow each other so closely that they cannot be demonstrated by an ordinary galvanometer. They can be demonstrated by a very sensitive electrometer (capillary electrometer) or by a special apparatus in which the action upon a magnetic needle is intensified by a series of action currents moving in the same direction and rapidly following each other through the galvanometer (Bernstein's repeating differential rheotome).

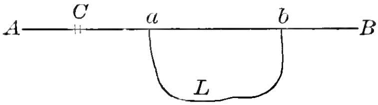


FIG. 17.

Cut a nerve across, place one electrode of the galvanometer on the transverse section and the other on the longitudinal surface. A current will pass through the galvanometer from the longitudinal to the transverse section (**current of rest**). At the cut surface the nerve immediately begins to die, and this is accompanied by processes which make that part of the nerve negatively electrical to the sound part. If in such a case a certain point in the longitudinal surface be stimulated, the intensity of the current of rest is decreased, that is, it undergoes a **negative variation.**

Aside from these electrical changes, the nerve impulse can only be detected by the effects which it has upon the end-organ (muscular contraction in the motor nerves, sensation in the sensory nerves).

2. **Laws of conductivity of nerves.**

(*a*) *Isolated conduction.*—In a nerve trunk composed of many fibres the impulse does not pass from one fibre to another.

(*b*) *Double conduction.*—A nerve artificially stimulated at a certain point conducts the impulse not only in the direction in which it is conducted under physiological conditions, but also in the opposite direction.

The nerve supplying the gracilis muscle of the frog divides into two branches, of which the one supplies the upper and the other the lower half of the muscle. At the forking of the nerve, the axis-cylinders divide, so that each axis-cylinder gives a branch to the lower and to the upper half of the muscle. If the muscle is cut transversely without injury to the fork of the nerve and one of the branches of the fork be stimulated, both halves of the muscle contract. Hence the impulse of the stimulated nerve passes not only in the centrifugal but also in the centripetal direction, and then, in the other branch, passes in the centrifugal direction.

The electrical phenomenon also spreads in both directions from the place artificially stimulated.

(*c*) *Velocity of the impulse.*—The velocity of the nerve impulse in an excised frog nerve, at room temperature, is 27 metres per second. In man it has been variously stated (between 30 and 60 m per second).

The velocity of the impulse is measured as follows: Take a frog muscle-nerve preparation and stimulate the nerve in two places, one at a place as near to, the other as far removed from, the muscle as possible. Determine the difference in latent period (the lapse of time between the stimulation and the beginning of contraction). This can be done best by graphically recording the contraction. The latent period following the stimulation of the point far removed from the muscle is greater than that following the stimulation of the point near the muscle. The difference between the latent periods is the time it takes for the impulse to travel the distance between the two points stimulated. From this it can be calculated how great a distance the impulse travels in one second.

Experiments based on the same principle have been made upon human beings, but the results are not constant.

3. **Stimulation and changes in irritability.**—The stimulating influences in many cases also produce changes in irritability and conductivity. Hence we may properly consider these actions collectively.

(*a*) *Mechanical influences.*—Hitting, pulling, squeezing, cutting, and drying stimulate the nerve, but also destroy its irritability and conductivity.

(*b*) *Thermal influences.*—Temperatures above 45° C. and below freezing-point destroy irritability and conductivity. Within the limits of temperatures which are not injurious, irritability and conductivity increase with the temperature. Sudden great changes in temperature stimulate, e.g. touching a nerve with a red-hot needle.

(*c*) *Chemical influences.*—These may be classified as:

1. Those which destroy irritability and conductivity without previously stimulating, e.g. acids, ammonia.

2. Those which first stimulate and then paralyze, e.g. concentrated salt solution, glycerin.

If a part of a motor nerve is acted upon by carbon dioxide, that part of the nerve loses its irritability for electrical stimulations, but does not lose its conductivity; for if the stimulation is applied above the place acted upon by the carbon dioxide, the impulse is still carried to the muscle. Hence irritability and conductivity are to a certain extent independent of each other.

(*d*) *Electrical influences.* — A constant current passed longitudinally through a stretch of nerve of sufficient length causes:

1. When made, stimulation and increased irritability at the kathode (place of exit of current); decreased irritability and conduction at the anode (place of entrance).

2. When broken, decreased irritability and conduction, for a short time, at the kathode; stimulation and also increased irritability at the anode, lasting for a short time. Stimulation by the electrical current which, in a motor nerve, is manifested by the contraction of the muscle, as a rule takes place only at the moment of the making and the breaking of the current (make and break contraction); more rarely it stimulates for some time during its passage through the nerve (make-tetanus) and for some time after the breaking (break-tetanus). Hence the extent of stimulation of a nerve depends chiefly on the changes in the strength of the current, not upon its absolute intensity. Changes in the strength of the current are the more effective the more rapidly they take place. For this reason, when the current is not suddenly made or broken but is made and broken gradually, no contraction results. The make contraction is stronger than the break contraction, so that a feeble but still active current produces a contraction only at the make.

The electric current does not stimulate if it passes transversely through the nerve.

In Fig. 18 let *N* be the nerve of a muscle-nerve preparation, and let the current enter at + and leave at –. Determine the latent period for the make and break contraction (in a similar manner as in determining the velocity of the impulse, page 219). It will be found that the latent period of the make is greater than that of the break contraction. If now the current is passed through the nerve in the opposite direction, it will be found that the latent period of the make is smaller than that of the break contraction. The difference in these latent periods corresponds to the time taken by the impulse to travel through the piece of nerve between the two electrodes. This proves that the stimulation of the making of the current takes place at the kathode, while that of the breaking occurs at the anode.

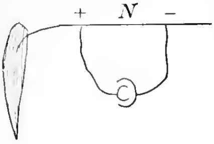


Fig. 18.

The changes in the irritability which the current produces at the electrode are investigated as follows:

The nerve is stimulated near either electrode of the constant current by a stimulus of constant strength, first before the constant current is passed through the nerve, and then while the constant current is passing through the nerve. Observe whether the contraction in the second case is larger or smaller than that in the first.

The irritability is changed during the entire passage of the current. This condition of changed irritability produced by the current is called *electrotonus;* the condition of increased irritability at the kathode is called *katelectrotonus*, the condition of decreased irritability at the anode is called *anelectrotonus.* We may express these observations in the law: The appearance of katelectrotonus and the disappearance of an electrotonus stimulate.

The decreased conductivity occurring at the anode during the making and, for a short period, at the kathode during breaking, is so great, when strong currents are used, that the nerve at these places loses its conductivity altogether. If a part of a nerve which has lost its conductivity is situated between the place stimulated and the end-organ (muscle), the stimulation has no result. This occurs in the following cases:

(1) During making, when the anode lies between the end-organ and the kathode.

(2) During breaking, when the kathode lies between the end-organ and the anode.

Law of contraction.—From the above-mentioned facts the following relations between the stimulation of a muscle and the strength of a current and its direction through the motor nerve can be formulated:

Strength of Current.		Ascending Current.	Descending Current.
Weak	Make Break	Contraction Rest	Contraction Rest
Moderate	Make Break	Contraction "	Contraction "
Strong	Make Break	Rest Contraction	Contraction Rest

The current is *ascending* when it passes through the nerve from the muscle to the centre; it is *descending* when it passes from the centre to the muscle.

The law of contraction may be explained thus: In a weak current only a stronger stimulus is active, i.e. the appearance of katelectrotonus stimulates; not so the disappearance of anelectrotonus, hence a contraction occurs only by the making. In a moderate current both the appearance of katelectrotonus and the disappearance of anelectrotonus stimulate, hence both a make and a break contraction result.

In a strong ascending current the make contraction fails, because the stimulation at the kathode cannot pass through that part of the nerve where the conductivity has been decreased at the anode. In a strong descending current the break contraction fails, because the stimulation at the anode cannot pass through the non-conducting part of the nerve at the kathode.

A current passing through a stretch of medullated nerve spreads throughout the whole nerve; also to that part of the nerve beyond the electrodes. If the two electrodes of a galvanometer are placed upon the nerve exterior to the part stimulated, a current passes through the galvanometer because of this spreading. This phenomenon is of physiological interest, for this spreading is due to a peculiar polarization of *living* nerve fibres. This spreading of the current cannot be demonstrated in a dead nerve. The whole phenomenon has been called physical electrotonus in distinction from physiological electrotonus (change of irritability).

The electrical resistance of the nerve in the direction of the fibre is 2½ million, in the transverse direction 12½ million, times as great as that of mercury.

Induced currents stimulate at the kathode only, hence act as weak currents in respect to the law of contraction.

The uninjured motor nerves in the human body seem to follow other laws of contraction than the excised nerves of a nerve-muscle preparation. When one electrode is placed on the skin above a nerve to be investigated and the other on some indifferent part of the body (back, neck) remote from the first electrode, a make contraction follows the feeblest but yet effective current when the electrode placed on the nerve is the kathode (kathode-make contraction). A little stronger current produces anode-make and anode-break contraction (when the electrode on the nerve is the anode), and, in a very strong current, also the kathode-break contraction. This apparent deviation from the law of contraction is due to the nature of the spreading of the current in the human body. The nerve, in this case, is traversed by the branching currents in diagonal and transverse directions, not merely longitudinally as in the excised nerve.

(*c*) Irritability and conductivity depend also upon normal vital conditions. Not only do excised nerves gradually lose their irritability and conductivity, but also nerves which have lost (by cutting, disease) their normal connection with the nerve cells. A nerve thus severed dies, the axis-cylinder and the medullary sheath disappearing and connective tissue being deposited. Sometimes regeneration of the nerve trunk still connected with the cell takes place.

A change in the irritability of the nerve by fatigue has not yet been definitely proven.

Nothing is known concerning the chemical composition of the real nerve-substance. No processes of metabolism have ever been demonstrated in the stimulated or unstimulated nerve. The metabolism is, at any rate, even in stimulated nerves, very slight, for nerves do not appear susceptible to fatigue, and the supply of blood to them is small.

Neurokeratin is found in the neuroglia; fat, cholesterin, lecithin, and protagon, in the medullary sheath.

4. **The effect of the conduction of the impulse.**—The nature of the result of the conduction of the impulse to the end-organ does not depend upon the nature of the stimulation, but upon the nature of the end-organ. For example, each effective stimulation of a motor nerve is followed only by a muscular contraction, of a secretory nerve by secretion, of a sensory nerve only by sensation. In the last case only that kind of sensation is produced which is specific for the sense cell of the organ acted upon.

The nerve fibres may be classified as to the direction in which they normally carry the impulse as:

1. Centrifugal (motor, secretory), conducting the impulse from the nerve cell to the peripheral organ.
2. Centripetal (sensory, nerves acting reflexly), conducting from a sense organ to a nerve cell.
3. Intercentral conduction from one nerve cell to another.

Besides conducting the impulses the nerve fibres have an influence on the nutrition of the organs which they innervate. After the nerves have been cut, the organs which they supply undergo disturbances of nutrition, e.g. the dying of a muscle after section of its nerves.

3. GENERAL PHYSIOLOGY OF THE NERVE CELLS

All the functions of the nervous system which we cannot explain from the known functions of the nerve fibres we ascribe to the nerve cell, for no other nerve elements are known to which they can be ascribed. These functions do not belong to the whole nerve cell, but to parts of the protoplasm. The nucleus has probably only a trophic function.

The trophic action of nerve cells is illustrated by the fact that nerve fibres separated from the nerve cells degenerate. In many cases this is also true for end-organs (muscles) supplied by these nerve fibres.

The nerve cells are irritable. Their physiological stimulation is of two kinds:

1. The stimulation originates by processes in the cells themselves—automatic activity. The automaticity is either tonic, when the impulse travels continuously through the nerve fibre connected with the cell, or rhythmic, when the impulse proceeds periodically down the nerve fibre. For example, lack of oxygen and accumulation of carbon dioxide stimulate the cells of the respiratory centre; they are conditions which the cell itself produces by its metabolism. The automaticity of the respiratory centre is rhythmic. The vaso-motor centre is also stimulated by lack of oxygen and accumulation of carbon dioxide; its automaticity is tonic.

2. The stimulation is carried to the cell by a nerve fibre. As the stimulation can be conducted from this cell to its axis-cylinder, there results the conduction of impulses from one nerve fibre to another through the nerve cell. The conduction of the impulse through the cell differs from that through the fibres in the following points:

(*a*) The cell is able, independently, to modify the impulse either

(*α*) In intensity: it can increase or decrease the strength of the impulse;

(*β*) In frequency of the impulse.

For example, the impulses which in the radiated reflexes (see page 231) affect the muscles are not proportional to the strength and frequency of the sensory stimulation which calls forth the reflex.

(*b*) The conduction is not double, but passes in one direction only. In the spinal cord, for example, the impulse passes, in reflex action, from the sensory nerve through the cell to the motor fibres, but never in the reverse direction. The electrical phenomena characteristic of the impulse cannot be called forth in the sensory nerve by the stimulation of the motor roots.

(*c*) The velocity of the conduction of the impulse through the cells is much less than that through the fibres.

From a physiological standpoint, the individual processes of conduction through the cells differ from each other only in the number of the impulses passing through the neurons, and in the modification of the impulse in the cells. From a psychical standpoint we may classify the processes of conduction through nerve cells into:

1. Conduction of impulses through the cells not accompanied by consciousness. This includes the reflexes, i.e. the transferring of an impulse from a centripetal fibre through a centre to a centrifugal fibre without resulting in consciousness, which may indeed occur against the will.

2. Psycho-physical processes, which are accompanied by consciousness. The transferring of the impulse from the sensory nerve fibre through the central nervous system to the motor nerve, which occurs voluntarily, is called "voluntary reaction," in distinction from reflex action.

The chemical processes which take place in the resting and the active nerve cells are not known. That they are intense is apparent from the fact that even temporary cessation of the blood supply soon causes injury. Death of the nervous system through asphyxia occurs in warm-blooded animals in a few minutes.

CHAPTER XVII

THE SPINAL CORD

Anatomy.—The cylindrical spinal cord is composed of a column of gray matter surrounded by a layer of white matter. In the cross-section the gray substance has the form of an H.

Each half of the white substance is divided by the gray substance into three columns, the anterior, lateral, and posterior. From between the anterior and the lateral columns the anterior roots of the peripheral nerves proceed, and from between the lateral and the posterior columns, the posterior roots. In each of the three columns the following separate bundles may be discriminated (compare Fig. 19):

1. In the anterior column:
    - (*a*) Direct pyramidal tract.
    - (*b*) Anterior ground bundle.
2. In the lateral column:
    - (*c*) Crossed pyramidal tract.
    - (*d*) Direct cerebellar tract whose anterior part is called Gower's column.
    - (*e*) Lateral bundles.
3. In the posterior column:
    - (*f*) Goll's column.
    - (*g*) Burdach's column.

The white matter contains medullated nerve fibres; the gray matter is chiefly composed of nerve cells.

The *functions of the spinal cord* consist in conducting impulses through fibres and cells. They may be divided into three main groups:

(1) The conduction of the impulses in the motor tracts from the brain through the cord to the peripheral nerves.

(2) The conduction of impulses from the peripheral sensory nerves through the cord to the brain.

(3) Conduction of impulses from the peripheral centripetal nerves through the cells of the gray matter of the cord to the peripheral motor nerves—reflexes.

1. THE MOTOR TRACTS

These are formed from fibres of both pyramidal columns, the cells of the anterior horns and the anterior roots.

The pyramidal column descending from the brain gives off, at various heights, fibres into the gray substance, hence the cross-section of this column decreases as it proceeds downward. The end-tufts of the pyramid fibres come into contact with the cells of the anterior horns, those of the crossed pyramidal tract are in contact with cells on the same side, while those of the direct pyramidal tract are in contact with cells on the opposite side. The fibres of the direct pyramidal tract cross in the anterior white commissure just before their ending at the cells.

The axis-cylinders proceed into the anterior roots from the cells of the anterior horn.

Pathological evidence shows that the paths just described are motor. There are diseases in which the motor nerves only are paralyzed, and in these cases the pyramidal columns and the cells of the anterior horns undergo

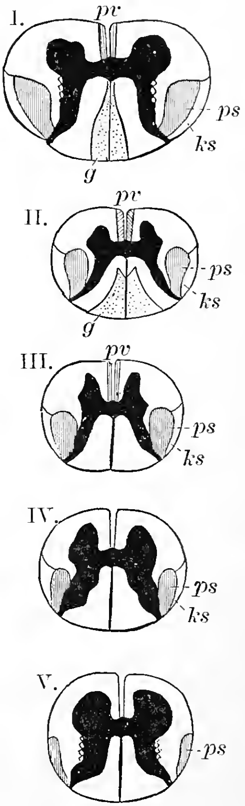


Fig. 19.—Cross-section of the Spinal Cord at Various Heights, demonstrating the Columns of the White Matter. (After Flechsig.)

I, at sixth cervical nerve; II, at third dorsal nerve; III, at sixth dorsal nerve; IV, at twelfth dorsal nerve; V, at fourth lumbar nerve. *pv*, direct pyramidal tract; *ps*, crossed pyramidal tract; *ks*, direct cerebellar tract; *g*, Goll's column.

anatomical changes (disappearance of the nerve tissue and the replacement of it by connective tissue). The results of anatomic investigations of the course of these fibres agree with the pathological evidences.

After transverse severing of the cord (by injury or disease) a secondary degeneration of the pyramidal column below the injury takes place. Since a nerve fibre, severed from its nerve cell, degenerates (see page 223), this leads to the conclusion that the cells of the pyramid fibres lie in the brain.

Of the nerves derived from the centrifugal tracts of the cord must be mentioned the nerves for respiration and perspiration and the vaso-motor nerves (see pages 75, 83 and 109). A few fibres (vasodilators and motor fibres for the intestine) are supposed to leave the cord by posterior roots.

2. THE SENSORY TRACTS

These are paths which, emanating from the fibres of the posterior roots, pass, either directly or by the interposition of cells throughout Goll's column through the direct cerebellar tract and, as scattered fibres, through the lateral bundle.

The peripheral sensory fibres end directly in the cells of the spinal ganglia. They are really elongated dendrites of these cells (see page 215). From these cells the axis-cylinders proceed through the posterior roots into the spinal cord and there separate into two large groups:

1. Fibres which cross the Burdach column diagonally, reach Goll's column and through this proceed upward to the brain.

2. Fibres the end-tufts of which come into contact with the cells of the gray substance. The neurites of these cells pass

(*a*) To the direct cerebellar tract on the same side, and in this tract proceed upward to the brain. The cells of these neurites lie in the columns of Clark, which are masses of cells on the median side of the basis of the posterior horns.

(*b*) Through the gray or white commissure to the other side, and pass upward as scattered fibres in the lateral bundles, or perhaps also in Gower's column.

Tabes dorsalis is a disease of the spinal cord in which the sensory nerves only are paralyzed, and the posterior roots and Goll's columns are degenerated. Hence Goll's columns are sensory tracts.

After transverse section of the spinal cord, secondary degeneration of the fibres of Goll's columns and the direct cerebellar tract above the section takes place; hence the cells of these fibres lie below the section.

Half-section of the cord.—If, by injury, one lateral half of the cord has been cut through, motor paralysis below and on the same side of the injury occurs, while on the opposite side there is chiefly loss of sensation. The injured motor columns lie, therefore, mainly on the same side as the corresponding peripheral motor nerves. The injured sensory columns lie, however, chiefly on the side opposite to the corresponding peripheral sensory nerves; this depends upon the above-mentioned crossing (2*b*) of the sensory fibres in the gray matter.

This brief review of the sensory tracts relates, in general, the facts as they are known at present; but the conditions, in detail, are much more complicated, for the long fibres in the spinal cord give off branches downward and laterally, ending in the gray matter. For example, each of the fibres of the posterior roots which enters the posterior columns divides into two long branches, the heavier one proceeding upward and finally, with Goll's column, reaches the medulla oblongata; the other going downward and, after a short course, ending in the gray matter. Both these branches give off collaterals which also end in the gray matter. The cells in the gray substance to which the ends of the descending and collateral branches go also give off neurites which, under the giving off of collaterals, form long tracts or, after a short course, end in the gray substance. Hence there is no such sharp distinction between the long sensory tracts and the reflex tracts to be described presently, as would appear from the above description.

3. REFLEXES OF THE SPINAL CORD

Nature of the reflex.—The reflex is the transferring of a stimulation from a centripetal to a centrifugal nerve through the centre. This occurs involuntarily. According to the effect of the reflex in the end-organ of the centrifugal nerve, we distinguish between reflex movement, reflex secretion, and reflex inhibition. The reflexes of the spinal cord are chiefly reflex movements.

The reflex tracts.—The connections of centripetal nerves with motor nerves which are necessary for the production of reflex movements may be:

(1) Direct. The end-tufts of the centripetal fibres and the collaterals are in direct contact with the motor cells.

(2) Indirect. Between the centripetal and the motor neurons other neurons intervene.

The direct and indirect tracts are illustrated in Fig. 20. In this figure *a* represents the motor cells and roots; *b* is a spinal ganglion with its root. The sensory collateral *r* joins the motor cells directly, forming a direct reflex tract. The sensory collateral *c* first joins the cell *d* whose axis-cylinders make connections with the motor cells through the collaterals *e, e, e.* This constitutes an indirect reflex tract.

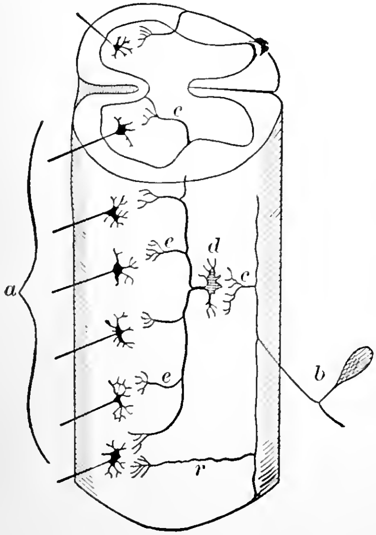


FIG. 20.

The direct reflex tract differs, therefore, from the indirect in that but two kinds of cells are intercalated in its course, namely, the cells of the spinal ganglion and the motor cells of the anterior horn. In the indirect tract one or more cells are placed between these two kinds of cells.

It is apparent that the union of centripetal with motor nerves may take place in a great many ways, as is also required by the manifold spreading of the reflex. The fibres of these reflex tracts, by which various heights of the gray matter are connected with each other, run chiefly in the anterior ground and lateral bundles and the columns of Burdach.

Classification of the reflexes.—The reflex movements executed by the aid of the spinal cord can most readily be studied in cold- and warm-blooded animals in which the action of the brain is excluded by a section between the brain and spinal cord.

According to the degree of spreading of the reflex movement we may discriminate:

1. Simple or partial reflexes. The stimulation of a sensory spot is followed by the movement of only one muscle or of a limited group of muscles. Example: knee-jerk. If the sensory nerve of the ligamentum patellæ is stimulated by hitting the ligament, the quadriceps femoris muscle contracts by reflex action and the lower part of the leg is thrown forward.

2. Radiated reflexes. Stimulation of a sensory area results in the contraction of large groups of muscles or of all the muscles of the body. We may classify them as:

(*a*) Orderly radiated reflexes. The stimulation is followed by a movement with the purpose of removing the stimulus or fleeing from it. If, for example, the leg of a decapitated frog is moistened with a drop of acid, the frog wipes off the acid; if the foot is pinched or pricked, it tries to flee. These reflectory defensive movements can also be observed in man during sleep.

The movements appear to us as voluntary movements, but whether they are accompanied by consciousness in the cells of the spinal cord cannot be determined, for we have no knowledge of any subjective perception in the cells. It is of interest to note that the cells of the spinal cord are able independently to change the afferent impulses into a purposelike muscular activity and are, therefore, from a physiological standpoint, not different from the cells of the cerebral hemispheres in which the psycho-physical processes take place.

(*b*) Disorderly radiated reflexes or convulsive reflexes.

By stimulation of a sensory spot, uncoördinated contractions of larger groups of muscles, even of all the muscles, may take place. Examples: convulsions during teething; convulsions in strychnine poisoning. In adults convulsive reflexes seldom occur, and only after very strong stimulation (in intense neuralgia).

As a stimulation of any sensory fibre may call forth convulsive reflexes, connections between all the sensory fibres and all the motor fibres must exist. These connections are normally irritable, but not all to the same extent, so that the impulse radiates over certain tracts and thus causes orderly reflexes.

Reflex time is the time elapsing between the entrance of the impulse into the spinal cord and the passing out through the motor paths. It is determined by measuring the time elapsing between the beginning of the stimulation and the beginning of the contraction, and subtracting from it the latent period of the muscle and the time taken by the stimulation to travel through the sensory and motor nerves. The reflex time is 0.008–0.015 second.

Influences affecting the reflexes.—Reflex action depends upon

(α) *The strength of the stimulus.*—To call forth a reflex the stimulus must be of a certain strength. Very strong stimulations, however, can inhibit the reflexes. The reflex time is, within certain limits, the shorter the stronger the sensory stimulation.

(β) *The number and sequence of the stimuli.*—A greater number of successive and weaker currents can more readily call forth reflexes than a single strong induction current.

(γ) *The place of stimulation.*—The reflexes are more easily called forth by stimulation of the sensory apparatus in the skin than by direct stimulation of the nerve trunk.

Reflex irritability is *increased* by certain poisons (strychnine) and during tetanus. It is greater in children than in adults.

It is *decreased* by certain poisons (chloroform, morphine, alcohol). In cold-blooded animals it increases with the temperature.

Inhibition of reflexes.

1. Many reflexes can be inhibited by volition. But we cannot voluntarily inhibit reflexes which are produced by muscles which cannot be contracted voluntarily (e.g. the contraction of the muscles of the uterus, contraction of the pupil).

2. There are special reflex inhibition mechanisms which are not dependent upon volition.

It is supposed that in man the centres of such mechanisms lie in the ganglia of the brain, and that from it fibres pass down the gray matter of the cord and act, in a manner still unknown, upon the cells so that the reflex is inhibited. If the function of these fibres is abolished by transverse section of the spinal cord, the reflexes below the level of the section are increased.

In the frog reflex inhibition centres have been demonstrated in the optic lobes, the stimulation of which prevents the reflexes.

3. A reflex brought about by the stimulation of a sensory nerve can sometimes be inhibited by the simultaneous stimulation of another sensory nerve.

4. SPECIAL REFLEX CENTRES IN THE SPINAL CORD

There are in the spinal cord centres for certain movements which can be brought into activity reflexly.

(1) In the cervical region are centres for the pupil reflex:

(*a*) A centre for the dilation of the pupil, in the upper part of the cervical cord;

(*b*) A centre for the constriction of the pupil, in the lower part of the cervical cord.

This pupil reflex serves to regulate the amount of light entering the eye. For details see page 267.

(2) In the lumbar region:

(*a*) Micturition centre.

The action of the centre for the sphincter vesicæ is tonic. During micturition the tonus of the sphincter is decreased and the centre for the detrusor is stimulated. This process is called forth reflexly by the distension of the bladder, which stimulates the nerves of the bladder and thereby reflexly stimulates the detrusor and inhibits the sphincter.

(*b*) Defæcation centre.

The tonus of the centre of the sphincters ani is inhibited reflexly (by stimulation of centripetal nerves in the rectum by the accumulated fæces); peristaltic movements of the intestine are set up which, together with the pressure of the abdominal walls, remove the fæces.

(*c*) Centre for the erection of the penis, ejaculation, parturition (see third section).

CHAPTER XVIII

THE BRAIN

1. CONDUCTING TRACTS

The physiological significance of all the details of the course of the fibres in the brain which anatomy has demonstrated is not known. It is therefore sufficient for us to describe the chief conducting tracts.

I. *Course of the tracts from the spinal cord into the brain.*

A. *The motor tract.*—The crossed pyramidal tract forms in the medulla oblongata the so-called *decussation of the pyramids*, breaking through the anterior horn on its side into the anterior ground bundle of the other side and joining the direct pyramidal tract. From this point upward, the two pyramidal tracts accompany each other, passing through the pons, where they are crossed by cross fibres from the cerebellum, then through the centre of the crusta cerebri, the posterior limb of the inner capsule, and the corona radiata, to the cortex of the cerebral hemispheres.

On its course from the cerebrum to the decussation, the common pyramidal tract gives off fibres to the cells of the motor fibres of the cranial nerves. The fibres of the pyramids which come from both sides cross shortly before entering in the nerve nuclei to which they go.

B. *The sensory tracts.*

Goll's column, in the medulla called the funiculus gracilis, ends mainly in cells of the nucleus of the funiculus gracilis. From there, fibres penetrate forward through the gray substance and cross the fibres from the other side above and behind the decussation of the pyramids. This crossing is called the decussation of the fillet. After crossing, the fibres lie dorsal to the pyramidal tracts; they then join the sensory fibres which, having perhaps already crossed in the cord, run upward in the lateral bundles. The common sensory tract thus formed, called *fillet*, passes upward through the pons and the crura cerebri. Thence a part of the fibres go to the ganglia of the corpora quadrigemina; another part, crossing the ventro-lateral nucleus of the thalamus opticus, pass, always posterior to the pyramidal tract, through the posterior limb of the internal capsule into the corona radiata to the cortex of the cerebral hemispheres.

In their course the fillets receive fibres originating from masses of cells in which the sensory cranial nerves, after entering the brain, end; these fibres cross before joining the fillet.

The nuclei of the motor and sensory cranial nerves lie in the upward prolongation of the gray matter which forms the floor of the fourth ventricle and, above it, the aqueduct of Silvius. The cranial nerves, except the optic and olfactory, are analogous to the spinal nerves. The optic nerve originates from the group of ganglia in the anterior lobe of the corpora quadrigemina and the lateral geniculate body. The olfactory nerve proceeds directly from the cerebral hemispheres.

2. The *direct cerebellar tracts* pass through the restiform body [inferior cerebellar peduncle] to the cerebellum, where they end in the gray matter of the worm. Besides this connection of the cerebellum with the spinal cord there are other fibres which unite the cerebellum with the cerebral hemispheres. They are:

(*a*) Fibres which pass from the anterior and posterior cortex of the cerebral hemispheres through the anterior and posterior limbs of the internal capsule and the crura cerebri to the nuclei of the pons. Thence they proceed backward to the cerebellum through the middle peduncle of the cerebellum—frontal, temporal, and occipital regions being thus joined to the cerebellum.

(*b*) Fibres which proceed from the cerebral hemispheres and, with the fillet, pass through the thalamus opticus into the red nucleus of the crura cerebri; thence to the other side through the pedunculi cerebelli into the cerebellum.

C. The short tracts of the spinal cord, which must be regarded as reflex tracts and which run in the anterior ground bundle and the Burdach column, cannot be traced as separate tracts in the brain. There are also, no doubt, many such pathways in the brain which connect the nerve cells and serve as reflex tracts, for in the brain many reflex processes take place.

II. In the cerebral hemispheres there are still a great many fibres which connect various parts of the cerebral hemispheres with each other. These are:

(1) Fibres in the corona radiata to the large ganglia of the base (thalamus opticus, nucleus lenticularis, nucleus candatus).

(2) The *association fibres*, by which various parts of the right and left half of the cerebral cortex lying on the same side are connected with each other.

(3) The *commissural fibres* which unite the right and left half of the cerebral cortex. They pass through the corpus callosum and the anterior commissure.

The association and commissural fibres are the conducting paths in psycho-physical processes which are the bases of the psychical phenomena (the utilizing of the sensation in formation of concepts, etc.).

2. CENTRES IN THE MEDULLA OBLONGATA

The medulla oblongata is a part of the central nervous system which is of special importance for the maintenance of life. It contains the centres for the regulation of certain processes which provide for the maintenance of normal metabolism (centres for respiration, circulation, and the movements and secretions of the alimentary canal). The great importance of these centres for the life of the animal is apparent from the fact that destruction of the medulla oblongata is immediately followed by death, while the destruction of other centres of the central nervous system is not directly fatal. The centres of the medulla oblongata have already been mentioned in the chapter on metabolism and their properties have there been described in detail, so that a simple enumeration will suffice here.

1. **The respiratory centre** (see page 83). By this centre the muscles which cause alternate inspiration and expiration (the diaphragm and the external intercostal for inspiration, the internal intercostal for expiration) are stimulated in an orderly manner. Its activity is dependent upon the need of oxygen by the body, for lack of oxygen and accumulation of carbon dioxide in the blood act as normal stimuli for respiration. Reflexly the respiratory centre is regulated by centripetal nerves, namely, the fibres of the vagus leading from the lungs to the centre. The inspiratory fibres of the vagus are stimulated during expiration, while the expiratory fibres are stimulated during inspiration.

2. **The centres for the organs of circulation** (see page 74). These are:

(*a*) The cardio-inhibitory centre (of the inhibitory vagus fibres).

(*b*) The centre for the sympathetic nerve from the cervical and the first thoracic ganglia, which carry the accelerating fibres to the heart.

(*c*) The centre for the constriction of blood vessels.

(*d*) The centre for the dilation of the blood vessels.

These centres serve to regulate the pressure of the blood stream and its distribution in the various parts of the body according to existing needs, by means of changes in the number and strength of the heart-beats and in the tonus of the muscles of the blood vessels.

The cardio-inhibitory centre and the vaso-constrictor centre are tonic. They are stimulated by lack of oxygen and accumulation of carbon dioxide in the blood. It appears that this stimulation serves to protect the heart from too speedy exhaustion during asphyxia, by decreasing its activity, and to compensate the resulting reduction in blood pressure by increasing the tonus of the muscles of the vessels.

The cardio-accelerating centre is also supposed to be tonic.

In general, the centres for the organs of circulation bring about many reflex actions. This is clearly apparent from the many and various actions by which these centres regulate the distribution of blood according to the needs of the body.

3. **Centres for certain movements and secretions of the alimentary canal** (see Chapters VII and IX). These are:

(*a*) Centres for *biting*, *sucking*, *mastication*, *deglutition*, *vomiting*, and perhaps also for the *movements of the stomach and intestines*.

The centres of biting, sucking, and mastication are voluntarily stimulated by the cerebral hemispheres; the other centres are not subject to the will. Deglutition takes place reflexly when the food has been pushed from the tongue behind the anterior pillars of the soft palate. "Empty swallowing" is made possible by the swallowing of saliva; without saliva it is impossible. The vomiting centre is not only stimulated reflexly, but can also be stimulated by psychical influence (sight of nauseous objects).

(*b*) Centre of salivary secretion, perhaps also for gastric, intestinal, and pancreatic secretions.

The stimulation of these centres takes place involuntarily, chiefly reflexly by the introduction of food in the alimentary canal; sometimes also, by psychical influences, sight of tempting food stimulates salivary and gastric secretion.

4. **Centres for the secretion of sweat and tears** (see pages 109 and 110).—These centres also are not stimulated voluntarily. The perspiration centre is directly stimulated by the raising of the temperature (heat) and also by lack of oxygen and the accumulation of carbon dioxide in the blood (asphyxia). Its activity is influenced by psychical conditions (sweat of fear).

The stimulation of the centre for lachrymal secretion takes place reflexly by stimulation of the conjunctival nerves, by strong light, and by psychical influences (weeping).

5. In the medulla oblongata is situated a spot which is connected with the glycogen and sugar formation in the liver (see page 146). Destruction of this centre (Piqûre) causes diabetes mellitus.

6. It is supposed that there exists in the medulla oblongata a centre which governs the reflex centres in the spinal cord and binds these centres together. It is supposed to be stimulated by lack of oxygen and accumulation of carbon dioxide in the blood, whereby convulsion of all the muscles in the body (asphyxia convulsion) is produced. Hence this centre is also called the centre of convulsion.

3. CENTRES IN THE CEREBELLUM, PONS, CORPORA QUADRIGEMINA, AND THE BASAL GANGLIA* OF THE CEREBRAL HEMISPHERES

The centres here located serve, as far as we are acquainted with their functions, to coördinate the movements of the skeletal and eye muscles. They may be divided into two groups.

1. **Centres for the coördinated compensatory movements maintaining the equilibrium of the body.**—These centres bring about a series of complicated orderly movements of the muscles so that the body keeps its equilibrium. When, for example, during standing or walking the equilibrium of the body is destroyed so that the body threatens to fall, the centres call forth such compensatory movements of the body muscles that the equilibrium and the normal position are regained. When the disturbance of the equilibrium is great, these actions can be readily observed, but these compensatory movements also take place when the position of the body deviates but little from the normal position. In this case the movements are less apparent and made so unconsciously that our attention is called to them only in certain

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* The basal ganglia are the thalamus opticus, nucleus caudatus, and the nucleus lenticularis.

diseases. The centripetal nerves which acquaint these centres with the position of the body are:

(*a*) The sensory nerves of the entire body which end in the muscles, tendons, and joints and which notify the centre of the relative position of individual members to each other and of the extent of the tension of the muscles.

(*b*) The optic nerve, which, by means of visual perception, acquaints the centre with the position of the body with reference to the objects of the external world.

(*c*) Certain fibres of the auditory nerve which end in the semicircular canals of the internal ear. These semicircular canals are sense organs for ascertaining the position and movements of the head.

In the execution of compensatory movements all the skeletal muscles take part.

As to the position of the centres, it is supposed that the coördinated movements of the lower extremities which chiefly function in locomotion and standing are governed by the *cerebellum*. The centres in the *corpora quadrigemina* are supposed to regulate chiefly the movements of the arms and hands.

Nothing is definitely known in detail concerning the position and limits of the centres. This is not surprising when it is borne in mind that in these centres the greater part of all the sensory and motor nerves are connected.

If, because of pathological changes and disturbances, interruptions in the connections between the afferent and efferent nerves for these centres or in the centres themselves take place, a disturbance in the coördinated movements of the body results. Hence in locomotor ataxia, in which the sensory nerves of the lower limbs are paralyzed, uncoördinated movements are made during walking. A person suffering with locomotor ataxia cannot stand erect when, by closing his eyes, he deprives himself of the only remaining means of orientating himself.

It is also possible that each centre or its tract *on one side only* may be paralyzed or abnormally stimulated by disease. The result is that the strength of the stimulation which is unconsciously imparted to the muscles is not equal on both sides. This results in abnormal positions and movements of the body, called *forced position* and *forced movements* because they are called forth involuntarily, indeed against the will. Forced movements in animals are, for example, the circus movements, clock-hand movements, rolling movements. In normal individuals forced movements may be observed during dizziness caused by rotation.

2. **Centres for the movements of the eyes.**—All the centres for the movements of the eyes lie in the gray matter forming the floor of the aqueduct of Silvius and the fourth ventricle (except the centre for closing the eyelid and the pupil reflex, see below and page 233).

(*a*) *The centres for the coördinated movements of both eyes.*—Concerning the functions of the individual centres, see page 280. Reflexes brought about by means of these centres are:

1. Involuntary movements of the eye (afferent impulse travelling through the optic nerve) by which the eye follows a moving object or by which the glance is thrown upon a luminous object.

2. Reflexes which are called forth by the sense organs for perceiving the position and movements of the head (semicircular canals of the ear, the centripetal nerve being the auditory). In this group belong the compensatory movements of the eyes which are involuntarily made when the head is moved, in order that the line of vision may remain on fixed objects.

Forced movements of the eye which occur in diseases of these centres and their paths are called nystigmus.

(*b*) Centre for the common *innervation of accommodation, convergence, and contraction of the pupil.* This is voluntarily stimulated during near vision.

(*c*) Centre for the *closing of the eyelids.* This is voluntarily or reflexly stimulated. Reflex stimulation occurs when the cornea or conjunctiva is touched (centripetal nerve is the first branch of the trigeminus), or by stimulation of the optic (blinking). The centrifugal nerve is the facial which innervates the palpebrarum orbicularis. The centre is situated in the medulla oblongata.

Centres for the *regulation of body temperature.* It is supposed by some authors that at the boundary between the medulla and the pons and in the basal ganglia there are centres which regulate the body temperature (see page 181), but the existence of these centres has never been definitely demonstrated.

Concerning the functions of the pineal gland nothing is known. It is regarded as a rudimentary eye.

4. FUNCTIONS OF THE CEREBRAL CORTEX

Psycho-physical processes take place in the cells of the cerebral cortex. The cerebral cortex is the seat of intelligence. Human beings in which the cortex of the cerebral hemispheres has been destroyed by disease, or animals in which it has been extirpated, are stupid; they take no notice of the external world, flee from no danger, do not independently seek their food, but they still manifest all the reflex movements the centres for which are located in the lower parts of the brain and spinal cord. In the animal world, the cerebral hemispheres and the number of the convolutions vary with the degree of intelligence.

The question whether the various psychical processes (sensations, thought, will) are localized in various definite parts of the cerebral cortex or whether all the parts of the cortex have the same value in psychical processes is at present variously answered by different authors. In higher animals (monkeys and dogs) it has been attempted to localize the functions of the cerebral hemispheres in two ways: either by observing the results of the stimulation of a definite part of the cerebral cortex, or by studying the disappearance of functions after removal of such a definite part.

By the first method it has been found that in the cortex there are a number of definite areas the stimulation of which is always followed by the contraction of a definite group of muscles. These areas, called motor areas, are, in general, situated in the central convolutions.

It is noteworthy that, under certain circumstances, stimulation of the cortex is followed simultaneously by the contraction of a certain group of muscles and the relaxation of the corresponding antagonistic muscles.

Partial extirpation often results in the temporary disappearance of functions, but after some time these functions reappear.

The results of experiments in stimulation and extirpation have been variously interpreted. The adherents to the localization theory hold that the effect of stimulation is produced by the stimulation of the motor centres which are employed in executing voluntary movements; the opponents of this theory hold that by this stimulation we do not really stimulate the centres, but the motor fibres which pass through the stimulated spot. The disappearance of a function by extirpation and the subsequent reappearance of that function depend, according to the adherents of the localization theory, upon the fact that the centre in which the function is located has been removed, but that subsequently other centres have gradually taken up this function. In the reappearance of the function after partial extirpation the opponents of the localization theory find support for their position that the psychical functions are not definitely localized. The first disappearance of the function they regard as due to the inhibitory influences caused by the injury [Hemmungserscheinungen].

Although at present the views concerning the localization of functions in the cerebral cortex of animals are at variance, yet there are many observations which render it almost certain that in man there is, to a certain extent, a localization of the psychical functions in the cerebral hemispheres.

The theory of the psychological topography of the human cerebral cortex is based upon:

(1) Anatomical and embryological investigations on the course of fibres, by which parts of the cerebral cortex are connected with each other as well as with other parts of the central nervous system.

(2) Upon clinical observations in connection with the results of pathological anatomical investigations.

Topography of the cerebral cortex of man.—The cerebral cortex of man may be divided into:

I. **Sensory areas,** i.e. centres in which the conscious sensations are formed. There are four such areas.

(1) **Centres for ordinary and tactile sensations.**—These lie in the anterior and posterior central gyri, the posterior parts of the frontal lobe, the paracentral lobe, and the gyrus fornicatus (compare Figs. 21–24).

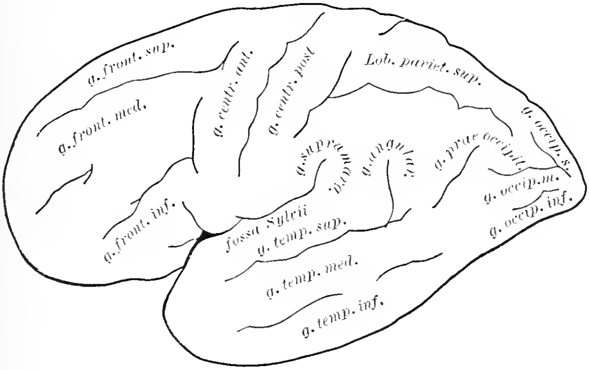

Fig. 21.

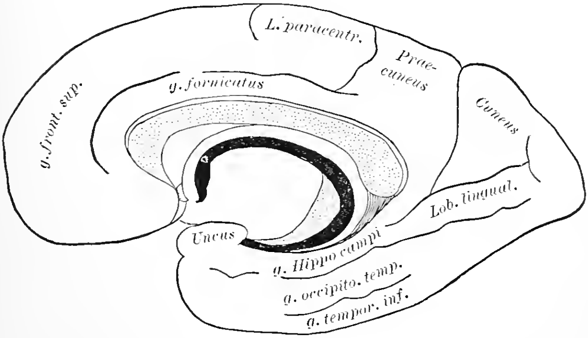

Fig. 22.

Convolutions of the Cerebral Hemispheres.

The centripetal fibres of the corona radiata of the tactile centres are the indirect processes of the posterior roots (fibres of the fillet and anterior peduncle which pass through the ventro-lateral nucleus of the thalamus opticus and thence into the corona radiata). In this area the sensations of the skin and organs are perceived.

We do not exclude the possibility that some of the indefinite organ sensations are perceived in centres situated lower down in the brain.

(2) The **auditory centre** lies in the median and the posterior part of the upper temporal convolution, and in the transverse convolutions of the temporal lobes. The centripetal corona radiata fibres of the auditory centre are the

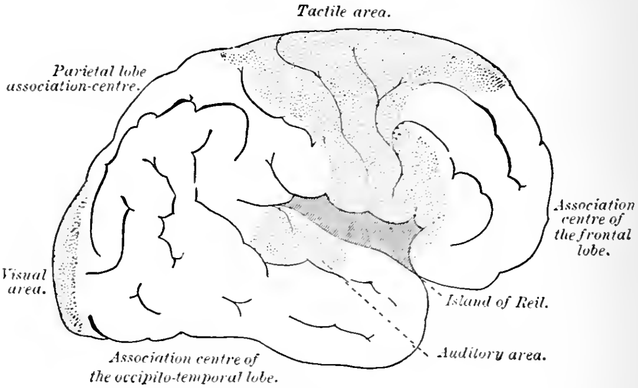

Fig. 23.

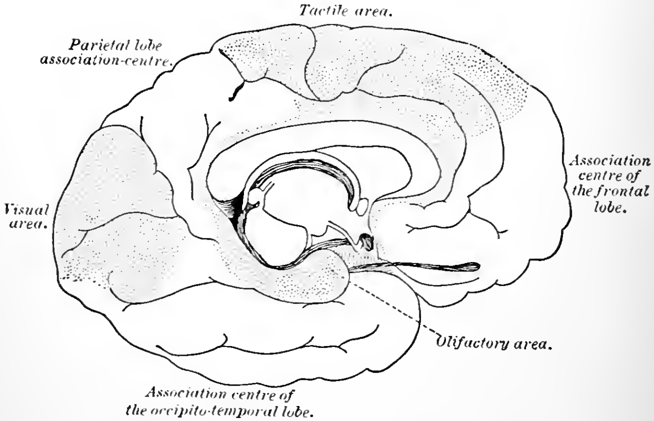

Fig. 24.

Sensory Areas of the Cerebral Cortex.

The sensory areas are dotted. In Fig. 23 the temporal lobe is slightly drawn downward in order to show the auditory centre. The island of Reil is seen at the shaded portion.

indirect continuations of the cochlear nerve (through the lateral fillet and the internal geniculate body to the corona radiata). The nervus vestibularis is supposed to be connected with the centres for ordinary and tactile sensations, not with the auditory centre.

(3) The **visual centre** lies in the cuneus, angular gyrus, and occipital. Their centripetal corona radiata fibres lie in the optic radiation of Gratiolet (continuation of the optic tract through the external geniculate body and anterior corpora quadrigemina into the corona radiata).

(4) The **olfactory centre** lies in the basis of the cortex of the frontal lobe, in the basal portion of the gyrus fornicatus, the island of Reil, the uncus, and the inner part of the temporal lobes.

The position of the centre of taste is not yet known.

II. **Motor areas** are centres by which the voluntary movements are inaugurated. They lie in the same portion of the cortex as the centres for tactile sensations. Their centrifugal corona radiata fibres are the pyramidal tracts the origin of which lies in the central convolution. In the upper part of this convolution originate the motor fibres for the lower extremities; in the median, those for the upper extremities; and in the lower portion, those for the face. In the posterior part of the lower frontal convolution, generally in the left cerebral hemisphere, are situated the motor centres for the muscles which function in the production of voice and speech (motor speech centre).

It is supposed that motor cells are also found in other sensory areas, but this is not agreed upon by all authors.

III. Those parts of the cerebral cortex which do not belong to the sensory or motor areas form, according to a new theory, the **association centres.** These centres function in the formation of concepts from the sense percepts. This view is, however, rejected by many authors.

It is supposed that the association centres differ anatomically from the other centres in the following respects. The association centres are supposed to be connected with each other and with the sensory areas chiefly by association and commissural fibres, and to contain relatively few corona fibres connecting it with the lower parts of the brain. The larger part of the fibres from the corona radiata are supposed to proceed to the sensory and motor areas. Moreover, the individual sensory areas are supposed not to be connected with each other by the association fibres, but only with the association centres.

Nothing is known concerning the nature of the psychophysical processes which underlie psychical phenomena. Up to the present time the investigations of these processes have been limited to their duration.

Reaction time is the time elapsing between the beginning of the action of a sense stimulation and a most rapidly executed muscular movement, e.g. of a finger. Both these times are registered.

The measurements of the reaction time are:

For optical stimulation	......	0.15–0.22	second.
" auditory "	......	0.12–0.18	"
" tactile "	......	0.09–0.19	"
" taste "	......	0.16–0.22	"

The reaction time is smaller for areas which are more frequently stimulated, e.g. the yellow spot, the tip of the finger, than for areas less frequently stimulated, as the periphery of the retina, skin of the arm. It is also dependent upon the degree of attention and practice, and upon the psychical attitude. Individual peculiarities also influence the reaction time.

When a very accurate registration of time must be made, for instance by a person noting the passage of a star across the thread of a telescope, the reaction time must be taken into consideration. The individual variations of the reaction time are brought into account by astronomers as "personal equation."

The more complex the psychical processes which intervene between the sense stimulation and the reaction, and the longer the time necessary for reflection, the greater will be the length of time between the beginning of stimulation and the reaction.

The elucidation of the psychical phenomena themselves (sensation, thought, volition, attention, memory, etc.) is the object of Psychology.

The interruption of psychical functions by **sleep** can be accounted for by the rest of the nerve cells of the cerebral cortex. How this rest is brought about is not known. The supposition that cessation in the activity of the cells is due to fatigue or lack of blood in the cells of the brain does not explain all the phenomena of sleep. Sleep also depends upon the stimulation of the sense organs. A person can be made to sleep by withdrawing the stimulation of the senses as far as possible. Customary sensations do not disturb sleep, strange sensations do. Sometimes the cessation of customary sensations awakes the sleeper. (The awaking of the miller when the mill stops.)

During sleep only the functions of the cerebral hemispheres cease; the other centres of the central nervous system (reflex and coördinated centres) may remain active. The eyelids are closed during sleep, the eyes are turned inward and upward, the pupils are contracted, respiration is slower. Metabolism is less during sleep than during waking hours.

Dreams are due to less profound sleep. *Somnambulism* and *hypnotism* are abnormal conditions of partial sleep.

Chemical composition and metabolism of the central nervous organs.—The *white substance* of the central nervous system contains 31% solids, including proteid and collagen 8%, lecithin 3%, cholesterin and fat 15%, protagon 3%; besides these, some substances containing nitrogen and phosphorus insoluble in ether (nuclein, neuro-keratin, jecorin) 1.5%; salts 0.2%.

The *gray substance* contains 18% solids, including proteid and collagen 10%, lecithin 3%, cholesterin and fat 3.5%, cerebrin and substances insoluble in ether 1%, salts 0.5%.

Nothing is known concerning the metabolism in the spinal cord and brain. Metabolism is not increased to an appreciable extent by mental work. The abundance of blood in the brain and the fact that stoppage of blood supply paralyzes the nerve cells in a few minutes, indicates that the metabolism is very energetic.

The *cerebro-spinal fluid* which surrounds the central nervous system and fills its cavities has a specific gravity of 1.005. It contains 1–1.5% solids, in which proteids are either absent or only present in traces. In it has been found a substance which reduces cupric oxide and appears to be pyrocatechin.

CHAPTER XIX

THE PERIPHERAL NERVES AND THE SYMPATHETIC SYSTEM

1. THE SPINAL NERVES

THE spinal nerves leave the spinal cord by the anterior and posterior roots.

The anterior roots are motor, the posterior chiefly sensory (Bell's law), but also contain a few motor nerves for the muscles of the intestines.

The nerve fibres innervating a muscle do not all lie in the same motor root, but a muscle is supplied with motor fibres from several anterior roots. These fibres join each other (plexus) and then proceed in a common trunk to the muscle.

The anterior roots contain fibres whose simultaneous stimulation calls forth movements of entire muscle groups which resemble certain coördinated movements frequently executed in life. For example, stimulation of the first dorsal root in a monkey results in the movements of the arm similar to those made in plucking fruit; stimulation of the seventh cervical calls forth movements of the arms similar to those made in climbing; by stimulation of the sixth cervical the hand is carried to the mouth. Perhaps the cells from which these nerves originate lie together in special cell-groups in the spinal cord, which may be regarded as coördinated centres. From these centres the nerve fibres accompany each other to the plexus.

The functions of the individual spinal nerves can be learned from their anatomical connections.

2. CRANIAL NERVES

I. The **olfactory nerve** is the nerve of smell. The olfactory bulb is the sub-cortical centre of this nerve; in it cells are interposed in the tract.

II. The **optic nerve** is the nerve of sight. The fibres of this nerve leave the brain by the optic tract. Their nearest nuclei lie in the anterior corpus quadrigeminum and in the lateral geniculate body. These parts are connected, on the one hand, with the cerebral cortex by means of fibres of the corona radiata and, on the other hand, with the more posterior nuclei of the brain, especially the nuclei of the nerves of the eye muscles. The optic tract passes over into the *chiasma*, where a part of the fibres cross. Thence they proceed to the eye as the optic nerve. Because of this partial crossing in the chiasma, the inner half of each retina is innervated by fibres from the opposite side of the brain, while the outer half receives fibres from the same side of the brain.

III. The **oculo-motor,** IV. the **pathetic** (trochlear), and VI. the **abducent** are the motor nerves for the external and internal eye muscles (except the dilator of the pupil) and the levator palpebræ superioris. The trochlear innervates the superior oblique, the abducent the rectus externus, the oculo-motor all the other eye muscles.

V. The **trigeminus** contains:

1. *Sensory fibres* for the whole head except the jaws and ears, which are supplied by the glossopharyngeal and the ramus auricularis vagi.

2. *Motor fibres* for the muscles of mastication (temporal, internal and external pterygoid, and masseter); also for the tensor palati mollis, mylohyoid, the anterior belly of the digastric, and the tensor tympani.

3. *Secretory fibres* for the tear glands.

The lingualis trigemini nerve contains secretory fibres (for the submaxillary and sublingual glands); also vaso-dilators and fibres for taste, which, however, originally leave the brain in company with the facial and glossopharyngeal and through the corda tympani reach the lingual. Besides these, the trigeminus contains vaso-motor and secretory nerves for the sweat glands of the face, which, however, are derived from the sympathetic.

VII. The **facial** contains motor fibres for all the face muscles, for the stylohyoid and the posterior belly of the digastric, and for the stapedius muscles. It also contains fibres which reach the sphenopalatinum ganglion through the petrosus superficialis major; thence they proceed to the levator palati mollis and azygos uvulæ. Besides these the facial contains secretory and vaso-dilator fibres which, in the chorda tympani, join the lingualis and with this proceed to the salivary glands.

VIII. The **auditory** contains, in the nervus cochlearis, the nerves of hearing. It also contains, in the nervus vestibularis, fibres which proceed from the semicircular canal of the internal ear, the organ of the sense of equilibrium, to the brain. These fibres reflexly influence the coördinated movements of the body for maintaining its position and equilibrium.

IX. The **glossopharyngeal** contains:

1. *Sensory* fibres for the posterior parts of the tongue, pillars of the fauces, tonsils, jaw, and epiglottis.

2. *Motor* fibres for the stylopharyngeal muscles and the median pharyngeal constrictor.

3. Nerves of *taste*. The nerves supplying the posterior part of the tongue proceed thither directly. Those supplying the anterior part pass from the petrosus ganglion of the glossopharyngeal through the tympanic plexus to the geniculate ganglion of the facial, thence they proceed through the chorda tympani to the lingual. It is supposed that some of the taste nerves of the glossopharyngeal pass through the tympanic plexus and the Jacobson's anastomoses to the nervus petrosus superficialis minor, otic ganglion, lingual, etc.

4. *Secretory* fibres which pass through the Jacobson's nerve and the nervus petrosus superficialis minor, etc., to the parotid glands.

X. **Vagus** and XI. **spinal accessory** form together a mixed nerve whose centrifugal fibres originate from the accessory, and the centripetal from the vagus. The external branch of the accessory contains motor fibres for the sternocleido-mastoid and the cucullaris muscle. The common vago-accessory send fibres

(1) To the circulation apparatus:

(*a*) The inhibitory fibres.

(*b*) Sensory and reflex-acting (depressor) to the heart.

(2) To the respiratory apparatus:

(*a*) Motor fibres for the muscles of the larynx (in the superior laryngeal for the crycothyroid, in the recurrent laryngeal for the other muscles) and for the bronchial muscles.

(*b*) Sensory fibres for the larynx (laryngeal superior), trachea, and lungs.

(3) To the muscles of the alimentary canal:

(*a*) Motor fibres for the movement and peristalsis of the esophagus, stomach, and intestine.

(*b*) Sensory fibres for the esophagus and stomach.

(*c*) Secretory fibres for the stomach and probably also for the pancreas and glands of intestine.

In addition to these the vagus is supposed to contain fibres which regulate the sugar formation in the liver.

XII. The **hypoglossus** is the motor nerve for the muscles of the tongue.

3. SYMPATHETIC SYSTEM

The sympathetic nerves are connected with the central nervous system by the rami communicantes, which pass from the trunks of the spinal nerves to the sympathetic ganglia. The sympathetic contains the vaso-motor fibres for the entire body. These pass either directly to the vessels or first join the peripheral nerves and, in common with them, continue their course. The sympathetic also sends secretory nerves to the sweat glands.

Besides these the sympathetic contains:

(1) In the cervical region

(*a*) Fibres for the dilation of the pupil.

(*b*) Secretory fibres for the salivary and lachrymal glands.

(*c*) Cardio-augmentor fibres.

(2) In the thoracic region

(*a*) Cardio-augmentor fibres (from the first thoracic ganglion).

(*b*) The splanchnic nerve, which contains sensory nerves for the intestine, and inhibitory nerves for the peristaltic movements.

All the motor fibres contained in the splanchnic are involuntary. The sympathetic fibres are non-medullated.

CHAPTER XX

SENSE ORGANS IN GENERAL

THE sense organs are the apparatus in which the peripheral sensory nerves end and which are stimulated by external or internal influences. The sensory nerves take up the impulse and carry it to the central nerve organ.

The sense organs are built for the reception of "adequate" stimuli and are generally acted upon by these.

The adequate stimuli for the eye are the ether vibrations of certain length; those for the ear are certain vibrations of air.

The stimulation of the sensory nerves produces **sensations** in the cells of the cerebral cortex to which they lead.

The sensations may differ from each other in **quality** and **intensity.**

As differing in quality we regard, e.g., the different sensations of colors, or sounds, or smell, etc.; while the light and dark sensations, or the loud and low sound sensations, are regarded as differing in intensity.

Law of the specific energy of the sensory nerves.—The *quality* of the sensation is constant for each sensory nerve and is independent of the nature of the stimulus.

For example, the stimulation of the optic nerve always causes a sensation of light, whether the nerve be stimulated by the adequate or by some other stimulus (mechanical, electrical).

In what manner the specific energy of the sensory nerve is determined is not fully known. We know no differences in the structure or physiological stimulation processes in the nerve elements (fibres and cells) which could determine this difference in the specific energy of the sensory nerves.

It is to be noticed that the adequate stimulus does not objectively contain the quality of the sensation which it produces. For example, the vibrations of ether which act upon the eye have nothing to do with the notion of light. The conception of light consists only in subjective perception.

The *intensity* of the sensation is, other things being equal, dependent upon the intensity of the stimulus.

The **liminal intensity** of a stimulus is the feeblest stimulus still perceptible; the "difference-threshold" of the stimulus is the smallest perceptible difference in the intensity of two stimuli or the smallest perceptible change in a stimulus. The size of the "difference-threshold" varies with the absolute strength of the intensity of the stimulus. *The smallest perceptible change in the intensity of the stimulus is proportional to the absolute strength of the stimulus—Weber's Law.*

According to Fechner's psycho-physical law, the strength of the sensations is related to the strength of the stimuli as a logarithm to its number. The validity of Fechner's law is disputed by many authors.

Objections have also been made against the general validity of Weber's law.

Besides differences in intensity and quality we can discriminate between the duration of sensations, and in some (sight and tactile) between the space conditions (place and extent of sensation).

CHAPTER XXI

OPTICS

The adequate stimuli for the eye are certain **vibrations** of ether, called light because they call forth the sensations of light. In order that an object shall be clearly seen, rays of light must pass out from the object, which by refraction in the eye form an inverted real image of the object on the retina. The cones and rods are the elements of sight; they form a mosaic of nerve elements of which every point upon which light falls can be stimulated. Hence different object points can, by their stimulation of various retinal points, call forth separate sensations of light and can therefore be seen as distinct points.

1. DIOPTRIC MECHANISM

Physical observations.

1. If a ray of light (S_1, Fig. 25) passes from the medium M_1 into another medium M_2, it is refracted at the surface bounding the two media (f), i e. it takes another direction (S_2). The angle α which S_1 forms with the perpendicular l upon the plane f is called the angle of incidence. The angle β which S_2 forms with l is called the angle of refraction. The sine of the angle of incidence divided by the sine of the angle of refraction is, for any given pair of media, constant, and is called the **index of refraction.** When the index of refraction of one medium is given, the light passes from the air into that medium.

2. **Homocentric** rays, or rays coming from one luminous point, falling upon the spherical surface between two media, are refracted so that after the refraction they either cross each other at a point (the real image point) or, prolonged backward, unite in a virtual image point. This is strictly true only for a part of a bundle of

light, namely, for those rays which are approximately perpendicular to the surface.

3. In refraction at a spherical surface the following equation expresses the distance of the luminous and image point from the surface:

$$\frac{n_1}{a_1} + \frac{n_2}{a_2} = \frac{(n_2 - n_1)}{r},$$

in which n_1 is the index of refraction of the first and n_2 that of the second medium; r is the radius of the spherical surface; a_1

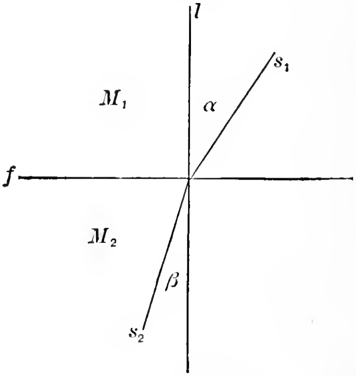

FIG. 25.

the distance of the luminous point; a_2 that of the image point. In this formula r is positive when the convexity of the surface is towards the side of the luminous point, negative when it is concave with respect to the luminons point. a_1 is positive when the rays entering are divergent, that is, come from a real object or luminous point; negative when the rays are convergent, that is, pass to a virtual object point. a_2 is positive for a real, negative for a virtual, image point. In Fig. 26, in which O is the luminous point and C the centre of curvature, all the values are positive. By means of the formula the position of the image for a given position of the luminous point can be found. The formula also teaches that an object or luminous point placed in the image point B has its image in the position of the previous luminous point O. Two points, of which the one as image point has the other for its object point, are called **conjugated points.**

The direction of the image point from a given luminous point is found by drawing a straight line from the luminous point through the centre of curvature C. This straight line is called the chief or **directing ray,** and the centre of curvature is called the crossing point of the directing rays, or the **nodal point.** The chief ray drawn through the vertex of the refracting surface is called the **optical axis.**

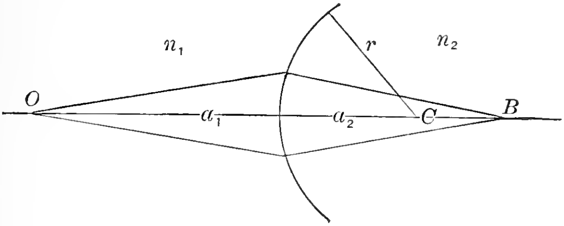

FIG. 26.

4. Rays parallel with the optical axis may be regarded as coming from an infinitely distant object point lying in the axis. After refraction they unite at a point on the optical axis, called the **second focal point;** its distance from the surface is called the **second focal distance.** Rays which, after refraction, run parallel to the optical axis, pass, before refraction, through the **first focal point,** whose distance from the surface is called the **first focal distance.** As in the formula for this case a_1 or a_2 is ∞, the focal distances designated by f_2 and f_1 are

$$f_2 = \frac{n_2 \times r}{(n_2 - n_1)}; \quad f_1 = \frac{n_1 \times r}{(n_2 - n_1)}.$$

The vertical planes erected upon the optical axis at the focal points are called the *focal planes.*

5. Construction of the image of a given object.

Let *mm* (Fig. 27) be a spherical surface separating the two media M_1 and M_2. Let K be the centre of curvature. AB is the optical axis of the system, F_2 the second, and F_1 the first, focal point. To find the image of the luminous point O_1, draw the directing ray O_1K. Also draw a ray from O_1 parallel to the optic axis; this cuts the surface at h_1, and from h_1 passes through F_2, and its prolongation cuts O_1K at b_1, which is the image point. In a similar way the image point b_2 of the luminous point O_2 is found. The image formed in this case is real and inverted.

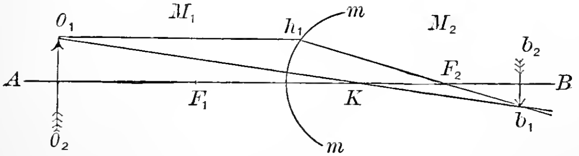

FIG. 27.

6. It can also be seen from Fig. 27 that the size of the object is to the size of the image as the distance of the object from the nodal point *K* is to the distance of the image from *K*.

7. An optical system may contain several spherical surfaces separating several refracting media. If all the centres of a spherical surface lie in a straight line, the system is called a **centred** system, and the straight line in which all the centres are located is called the optical axis. The refraction of such a system can be determined by finding the refraction of each surface successively according to the above formulæ.

8. A system in which the entering rays are converged is called a converging or **collecting system** [Sammelsystem]. (Parallel rays are converged; convergent rays are rendered more convergent; divergent rays are either rendered less divergent, parallel, or convergent, according to the original degree of divergence.)

I. **The dioptric system of the normal resting eye.**—The dioptric system of the eyes is a convergent system of three approximately concentric spherical surfaces placed between four media. The media are: air, aqueous humor, lens, vitreous humor. The surfaces of separation are the anterior surface of the cornea and the anterior and posterior surfaces of the lens. The optical axis is called the visual axis (see Fig. 28, f_1 f_2).

The posterior surface of the cornea is disregarded because it is parallel with the anterior surface and because the index of refraction of the cornea may be regarded as the same as that of the aqueous humor.

The indices of refraction of the aqueous humor and of the vitreous humor are 1.338, that of the lens is 1.455. The radius of the curvature of the corneal surface is 8 mm, of the anterior surface of the lens 10 mm, of the posterior surface of the lens 6 mm. The distance of the anterior surface of the cornea from the anterior surface of the lens is 3.6 mm, the thickness of the lens is also 3.6 mm. The retina lies 15 mm behind the posterior surface of the lens. From these data the dioptric action of the system can be found.

The indices of refraction can be determined only in the dead eye, but the radii and the distances of the surfaces can also be determined in the living eye.

The lens is composed of many layers, like an onion, and the individual layers have various indices of refraction, the index increasing as we proceed to the centre. Because of the order of the layers, the actual total index of refraction is somewhat larger than the index of the central layer.

The radii of curvature are determined from the size of the reflected image of a known object which is formed, by reflection, at the surface. To measure the size of these images accurately the *ophthalmometer* invented by Helmholtz is used.

It has been found by calculation that the dioptric effect of the eye can also be produced by a simple system, in which the lens is not present and is replaced by vitreous humor, and in which the reduction of refraction, due to omission of the lens, is corrected by giving the only remaining refractive surface (the surface of the cornea) a stronger curvature and a different position. The system is therefore reduced to a single spherical surface placed between *two* media (for the aqueous and vitreous humor have the same index of refraction). The radius of this surface is 5.017 mm; the distance of the centre of curvature (nodal point) from the anterior surface of the cornea in the real (not reduced) eye is 7.16 mm. The simplified system is called the **reduced or schematic eye,** and by its aid we can construct the refracted ray of light as indicated in Fig. 27. In Fig. 28 *ll* is the position of the surface of separation of the reduced eye.

Strictly speaking the system of the eye has two nodal points (K_1 and K_2, Fig. 28, which lie 6.96 and 7.37 mm behind the vertex of the cornea), but these lie so closely together that they may be regarded as one. The two nodal points have the following characteristic. A ray which, previous to refraction, passes in the direction of the first nodal point, passes, after refraction, through the second nodal point and parallel to its original course. Corresponding to the two nodal points there are also two spherical surfaces. The points where the optical axis cuts these two surfaces are called the *chief points* (h_1 and h_2, Fig. 28). The first chief point lies 1.94 mm and the second 2.36 mm behind the anterior surface of the cornea. Planes erected perpendicular to the optic axis at the chief points are called chief planes. The chief planes must be regarded as conjugated planes of such a nature that an object which, previous to refraction, is supposed to be located in the first chief plane, must have, after refraction, an image of the same size in the second plane.

The nodal, chief, and focal points of the eye are collectively called the *cardinal points* (cf. *infra*).

The second focal point of the eye lies 22.23 mm beind the vertex of the cornea, the first focal point 12.92 mm (f_2 and f_1, Fig. 28). The second focal plane nearly coincides with the retina. Images of infinitely removed objects having parallel rays fall on the retina. *Hence the normal retina can clearly see objects at an infinite distance.*

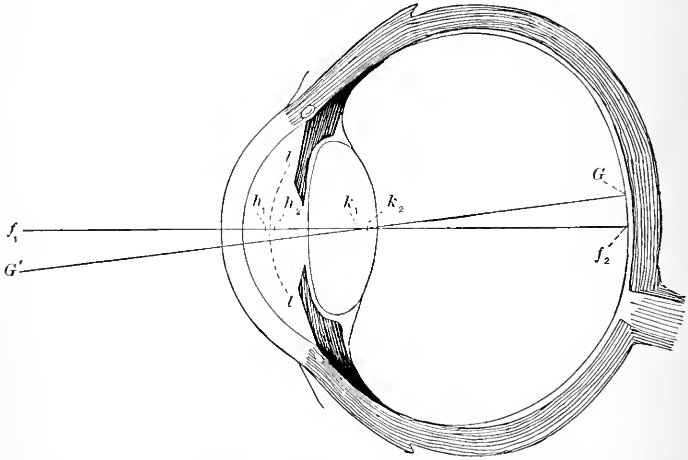

FIG. 28.—CARDINAL POINTS OF THE EYE (see text). *GG'* is the visual axis.

II. **Accommodation.**—The image of a near luminous point falls behind the retina of the resting eye and no image is formed on the retina. In its place a luminous circle appears, the *circle of diffusion*, because the rays have not yet united. As the circles of diffusion of a near luminous point overlap each other the image of a near object on the retina is not sharply defined, hence the resting eye cannot clearly see near objects.

In order to form upon the retina a sharply defined image of a near object, the refractive power of the eye is increased by increasing the curvature of the surfaces of the lens. This process is called **accommodation.**

In the condition of strong accommodation the radius of the anterior surface of the lens is 6 mm, of the posterior surface 5.5 mm; the anterior surface is also slightly pressed forward, the posterior surface remains in its position. For this condition also a reduced eye may be constructed, the radius of the spherical surface of separation being 4.53 mm, its centre of curvature lying 6.79 mm behind the vertex of the cornea. In this condition sharp images of objects 120 mm distant from the vertex of the cornea are formed upon the retina.

Purkinje-Sanson images.—The change in the curvature of the lens shows itself by changes in the size and position of the image reflected from the surfaces. If a candle is held on one side of the eye, three reflected images may be seen if the eye is looked at from the other side (Fig. 29, *F*). The first image, formed by the cornea, is upright and clear; the second, formed by the anterior surface of the lens, lies near and a little behind the first; the third, formed by the posterior surface of the lens, is small and inverted. If the eye is accommodated for near vision, *b* and *c* become smaller and *b* approaches *a* (Fig. 29, *N*); this is accomplished by the stronger curvature of the surfaces of the lens.

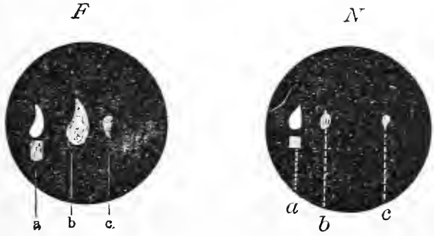

FIG. 29.

Scheiner's experiment.—In a cardboard make two pin-holes near each other. Place the holes near one eye and, the other eye being closed, look in the direction of a near point. If now the experimenter look past the point into the distance, the first point is seen double; if the near point is looked at, only one point is seen. Of the rays emanating from the near point two thin bundles pass through the pin-holes into the eye, which, when the eye is accommodated, unite to form one image point on the retina; but if the eye is not accommodated, they illuminate two different points of the retina because its two rays of light unite back of the retina.

Mechanism of accommodation (see Fig. 30).—The lens *L* lies inclosed in the two leaves of the capsule of the lens. The capsule of the lens at its border passes over into the zonule of Zinn, *zz* and z_1z_1, a folded membrane whose periphery is united with the choroid where this passes over into the corpus ciliare (*c*).

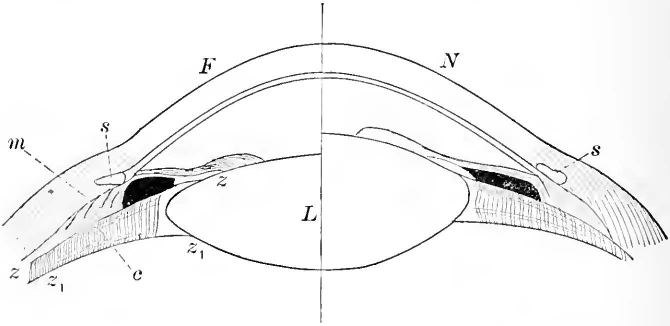

FIG. 30.—CHANGES IN THE LENS DURING ACCOMMODATION. (After Helmholtz.)

F, far vision; *N*, near vision; *m*, musculus ciliaris; *zz*, z_1z_1, zonule of Zinn; *c*, ciliary process; *L*, lens.

The intra-ocular pressure produced by the transudation of tissue fluid from the blood vessels into the inner part of the eye causes the coats of the eye to be taut, and thereby stretches the part at which the zonule is inserted into the choroid. Hence the zonule and the capsule of the lens are stretched and the lens is pressed together and flattened in its anterior-posterior direction. This is the condition of the lens in the resting eye (Fig. 30, *F*).

The fibres of the muscle of accommodation *m* (tensor of the choroid or ciliary muscles) in the ciliary body pass from the insertion point of the zonule to the place where the choroid has grown together with the boundary between the cornea and the sclerotic. By the contraction of these muscles the part at which the zonule is inserted is pulled slightly forward and inward (toward the axis of the eye) and thus shortened. This slackens the zonule and the capsule of the lens, and the lens, in consequence of its elasticity, bulges forward so that its curvature becomes greater (Fig 30, *N*).

The muscles of accommodation have smooth fibres.

The oculo-motor nerve supplies them with motor fibres which enter into the ciliary ganglion and thence proceed, as the short ciliary nerves, to the eye.

The accommodation muscles of both eyes are innervated simultaneously and to the same extent. Simultaneously with these the internal rectus and the sphincter iridis of both eyes are innervated, so that accommodation is always accompanied by convergence of the eyes and contraction of the pupils.

Measure of accommodation.—The point which the resting eye sees clearly is called the far point; the point which the most strongly accommodated eye sees clearly is called the near point. The range of accommodation is the distance of the far point from the near point. The power of accommodation is measured by the reciprocal of the near point minus that of the far point, hence for the normal eye, in which the near point is 0.12 m,

$$\frac{1}{0.12} - \frac{1}{\infty} = \frac{1}{0.12}, \text{ or } 8.3 \text{ diopters.}$$

This number expresses the refractive power which a convex lens must have in order to have the same dioptric effect as the eye normally has during strongest accommodation. The power of refraction (diopter) is expressed by the reciprocal of the focal length of the lens. A lens having the focal length of 1 m has the value of 1 diopter. The power of accommodation is therefore equal to that of a lens of 0.12 mm focal length. The power of accommodation decreases with age, because the lens becomes hard (presbyopia).

Anomalies of refraction (near-sightedness or myopia, far-sightedness or hypermetropia) are due to abnormal positions of the retina. In **myopia** the retina lies too far back, and parallel rays meet in front of the retina; hence to unite them on the retina, the refraction of the eye must be decreased by placing before it a diverging [concave] lens. In **hypermetropia** the retina lies too far forward, and parallel rays meet back of the retina; in order that in the resting eye they may unite in the retina, the power of refraction must be increased, which is accomplished by the converging [convex] lens. The normal eye is called **emmetropic**; in it the second focal point lies on the retina.

Periscopia is the power of the eye to see clearly points lying far aside from the axis of the eye. The laws thus far enunciated apply only to rays of light which are approximately parallel with the axis and which meet the refracting surfaces nearly at right angles. Rays from luminous points lying far to one side are not accurately united into an image point, but are quite well concentrated at two points on two small lines, of which the posterior one may be regarded as the analogue of an image point. The real image points of lateral and infinitely removed luminous points lie on a curved surface which approximately coincides with the curved surface of the retina. This is true, however, only for the unreduced eye. In the reduced eye the curved surface does not coincide with the retina.

Imperfection in the dioptric apparatus.

1. **Spherical aberration.**—If a bundle of light falls obliquely upon a spherical plane separating two media, the peripheral rays are more refracted than the central rays, hence the rays are not accurately united at one point. This is prevented in the eye by the facts that the surface of the cornea is not perfectly spherical, but is more strongly curved in the centre than at the periphery, and that the iris cuts off the peripheral rays.

2. **Chromatic aberration.**—The various colors of the spectrum are differently refracted, the violet being more strongly refracted than the red; hence the violet rays are brought to a focus sooner than the red rays. This ordinarily causes no disturbance in vision, but can be observed by covering half of the pupil of one eye with a piece of cardboard and gazing with this eye upon a light object. The borders of the object appear colored because of the chromatic aberration.

3. **Astigmatism.**—The curvature of the surfaces of separation may be unequally great in various meridians of the surface. Hence the rays of light from a light-bundle falling upon a given meridian will be refracted differently from those falling on another meridian and will unite at another place. Suppose that the meridian having the greatest curvature is at right angles to the meridian having the least curvature. It will be found that the cross-section of the bundle of light of parallel rays after refraction forms a straight line at two places, the first of which has the direction of the meridian

having the least curvature, and the second the direction of the meridian of greatest curvature. The normal eye is slightly astigmatic, the vertical meridian having the greatest curvature. Because of astigmatism, of a number of black lines all crossing at a common point only one is clearly seen; the others, especially the one at right angles to that clearly seen, are less sharply defined. Severe astigmatism causes disturbances in vision which may be corrected by the use of cylindrical glasses.

Entoptical phenomena.—Opacities in the refracting media, found in the normal as well as in the diseased eye (cells and fibres of the vitreous humor, accumulation of dust or flock of mucus in the cornea, etc.), hinder the passage of light and cast shadows on the retina which are seen as opaque objects in the luminous visual field. They can be seen especially well when a source of light is placed in the first focal point from which parallel rays pass through the vitreous humor. If the eye is moved, the apparent position of the opaque object also moves—muscæ volitantes. Among these also belong the shadows cast by the blood vessels (see page 270). The capillary stream of the retina can, under certain conditions, also be seen entoptically in the form of moving points.

III. **Function of the iris.**—The iris has two muscles (with smooth fibres):

1. The *sphincter of the pupil*, a circular muscle, by the contraction of which the pupil is contracted, is innervated by the fibres of the oculo-motor which pass through the ciliary ganglia and the short ciliary nerves.

2. The *dilator of the pupil*, radial fibres by the contraction of which the pupil is dilated. It is innervated by the sympathetic fibres which also pass through the ciliary ganglia.

The innervation of both muscles is tonic. Section of the oculo-motor causes dilation; section of the sympathetic, contraction of the pupil.

The **iris** is opaque because of its pigment. It serves:

1. As a *diaphragm* to cut off the peripheral rays and thereby prevent spherical aberration (see page 266).

2. To *regulate the amount of light* entering the eye. The more light the eye receives the more contracted the pupil. This change in the width of the pupil follows reflexly upon changes in the amount of light entering the eye. The

centripetal nerve of this reflex is the optic nerve. By this reflex contraction of the pupil the retina is saved from too strong illumination, since the smaller the pupil the less the light that enters the eye.

Normally both pupils are of the same size; the change in the pupil takes place in both eyes even when the light entering one eye is changed (consensual pupil reflex). The centres for this reflex lie in the cervical cord (see page 233).

The contraction of the pupil also takes place during accommodation and convergence of both eyes. The centre for this process is situated in the corpora quadrigemina (see page 242).

The pupil is (1) contracted by sleep and by poisons (physostigmin); (2) dilated by stimulation of many sensory nerves, muscular exercise, dyspnœa, poisons (atropin).

IV. **Ophthalmoscope.**—Only light falling upon the most anterior part of the eyeball enters the eye. Light falling upon the side does not enter the eye because of the opacity of the choroid and iris. The light which has entered the eye is reflected by the retina back to its source. Hence we cannot see the background of another person's eye because no light emanates from our own eye by which the observed eye is illuminated. But if a mirror, *S*, having an aperture in its centre (Fig. 31) is placed between two eyes, *A* and *B*, in such a position that it throws rays of light coming from

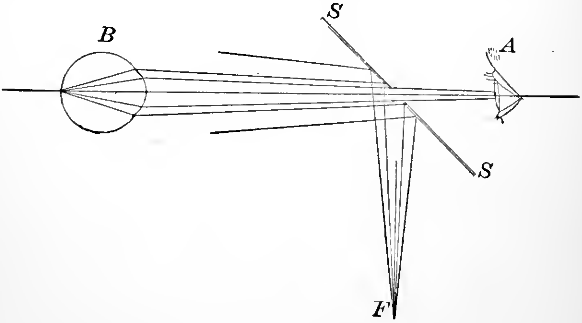

FIG. 31.

a light *F*, which is placed at the side of the head, into the eye *B*, a part of the rays reflected by the background of the eye leave *B* and pass through the aperture in the mirror into the eye *A*. The eye *A* then sees the background of the illuminated eye *B*. If both eyes are emmetropic and at rest, the light reflected by *B* passes out in parallel rays and *A* sees the back of *B* erect and enlarged. If the light leaves *B* in convergent rays (in case *B* is accommodated or myopic —as represented in Fig. 31), the image of the retina can be seen erect by placing a concave lens, making the rays parallel or divergent, between *A* and *B*. If a convex lens of sufficient strength is placed between *B* and *S*, the reflected rays form, at some point between *S* and the lens, a real and inverted image of the background of *B* which can be observed by the eye of the observer *A* (observation of inverted image).

In the albino, diffused light enters the eye through the transparent iris which contains no pigment; this light can illuminate the background of the eye. If this diffused light is prevented from entering the eye, as by placing a diaphragm in front of the eye, the background of such an eye also appears dark.

2. THE STIMULATION OF THE RETINA BY LIGHT. SENSATION OF LIGHT

The elements of the retina sensitive to light are the cones and rods. From them the stimulation passes through the nervous portion of the retina and through the optic nerve to the brain.

The nerve structure of the retina is found in the connective-tissue-supporting elements and is composed of three neurons placed one behind the other (see Fig. 32). They are:

(1) *Neuro-epithelial cells*, i.e. the cones (*z*) and rods (*s*) with their nucleated portion (cone and rod granules, z_1 and s_1), which are joined by processes to the outer processes of the

(2) *Bi-polar cells* (*b*). The inner processes of the bi-polar cells join the protoplasmic processes of the

(3) *Ganglionic cells* (*g*), whose axis-cylinders form the optic fibres.

In addition to these, still other cells and centrifugal nerve fibres have been found in the retina, but their function is not known.

The mosaic arrangement of rods and cones lies in the external layer of the retina (viewed from the centre of the eyeball). To arrive at them, light coming from the vitreous humor must first pass through all the other layers of the retina.

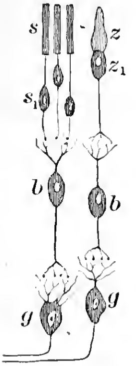

FIG. 32.—SCHEMATIC REPRESENTATION OF THE RETINAL NEURONS.

The outer layer of the retina in the *macula lutea* contains only cones; in the other portions it contains cones and rods. In the central part of the macula lutea, that is, in the *fovea centralis*, the cones have a diameter of 2–2.5 μ; at the periphery 6–7 μ; the rods have a diameter of about 2 μ.

External to the layer of rods and cones there is a layer of epithelial cells with delicate protoplasmic processes which reach down between the rods and cones.

That the cones and rods are the retinal elements for the perception of light is proven by the shadows which the blood vessels of the retina cast. In a dark room a light is held to the side of the eye (at *a*, Fig. 33), while the other eye is closed. The light illuminates the retina at the point *b*, which is found by drawing a line from *a* through the nodal point *K* to the retina. From *b* light is reflected by which other parts of the retina are illuminated; the cause of this sensation of light thus produced we refer to the external world, hence we see the visual field dimly illuminated. One of the rays reflected from *b* falls upon the retinal vessel *g*, and hence

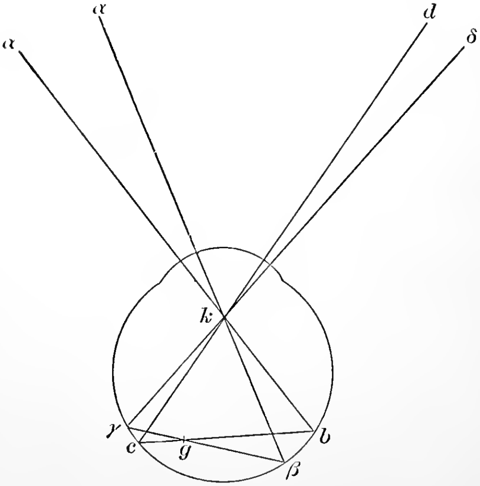

FIG. 33.

the point *c* of the retina will remain dark and we see a dark spot in the visual field in the direction *cd* (prolongation of a straight line drawn from *c* through the nodal point). The shadows cast by the retinal vessels upon the retina are perceived as black ramifying lines in the visual field. If now the light is moved from *a* to α, the apparent position moves from *d* to δ, as illustrated in the figure. From the extent of both movements the distance between *g* and *c* may be calculated, and it has been found that this corresponds to the distance between the vascular nerve-fibre layer and the layer of rods and cones.

The place where the optic nerve enters the eye [blind spot] is not sensitive to light, because at that place no rods and cones are present. This is demonstrated as follows:

Fig. 34.

Close the left eye, and with the right eye look at the cross *a* (Fig. 34) while the page is held about 25 cm from the eye. The black circle is then invisible because its image falls upon the blind spot.

It has been supposed that in the sensitive apparatus a substance, the so-called visual substance, is decomposed, and that this decomposition calls forth the stimulation.

I. **Objectively demonstrable changes in the retina produced by light.**—Changes in the retina produced by light have been demonstrated, but their relation to the sensation of light is not known.

1. **Visual purple** (rhodopsin) is a red pigment found in the external elongation of the rods. This is bleached by light, the color being restored in the dark and also in the excised eye (in rabbits in one half-hour, in frogs in one to two hours). The restoration proceeds from the pigment epithelium. Visual purple cannot be the only visual substance, for it is not present in the macula lutea of man, the place of direct vision (see page 277).

The visual purple can be extracted from a fresh retina by an aqueous solution of bile salts. This must be done in the dark or by a sodium light, because the extracted visual purple is bleached by daylight, not by red or yellow light. The composition of visual purple is not known.

2. In the dark the pigment of the epithelial layer in a frog collects in a cell body, while, in the light, it moves along the processes between the cones and rods.

The pigment is not directly necessary for the perception of light, for individuals in whom pigments are lacking (albino) are able to see.

3. In frogs and fishes the inner processes of the cones become shorter and thicker in the light.

4. In the illuminated retina certain electrical phenomena, connected with the irritation, have been observed, but their cause and significance are not known.

II. **Visual sensation.**

A. **The intensity of visual sensation.**—The intensity of visual sensation is dependent upon:

1. The *intensity* of the stimulus. The stronger the light the greater the intensity of the sensation. The sensibility for perceiving the difference in the intensity of different lights follows Weber's law (page 256).

2. The *size* of the illuminated portion of the retina. A small light object may appear darker than a larger but less luminous object.

3. The duration of the action of the light.

(*a*) *The rise of visual sensation.*—A considerable length of time, about 0.16 second, elapses between the beginning of the action of the light and the time that the sensation of light has reached its greatest intensity. Hence a bright light acting for a very short time may appear darker than a less bright light acting for a longer time.

(*b*) *Disappearance of the visual sensation; positive after-image.*—If the light disappears suddenly, the visual sensation remains for a short time. This is called the positive after-image. Upon this depends the well-known phenomenon that if, in the dark, a glowing coal is moved forward and backward, the coal does not appear as a luminous point at each place where it actually is, but as a fiery stripe corresponding to the path it describes. In this case, new points of the retina are stimulated before the sensation of the previously stimulated points has entirely disappeared.

The individual visual sensations produced by a series of light stimulations rapidly following each other blend into one visual sensation. Each individual stimulation increases and each interval between the stimulations decreases, to a certain extent, the retinal stimulation; but if the light stimuli follow each other sufficiently rapidly, the variations in the sensations are so small that they are no longer perceived. The intensity of the visual sensation in this case is as great as that produced by a correspondingly feebler light acting continually (*Talbot's law*).

(*c*) *Fatigue of the retina. Negative after-image or successive contrast.*—By long duration of the light, the intensity of the sensation is decreased because of the fatigue of the retina. A fatigued retina is less irritable than one not fatigued. If one looks for some time at a light field placed on a dark background and then at a uniformly light field, this does not appear uniformly light, but upon it is seen a dark area corresponding to the light field first looked at. This phenomenon is called negative after-image or successive contrast.

Adaptation or the adjustment of the retina to various intensities of light depends upon fatigue and restoration. If one enters from a light into a dark room, nothing is clearly seen at first because the retina is fatigued; gradually the retina becomes more irritable, being rested, and one sees much better in the dark. If one enters from a dark into a lighted room, the light at first blinds because of the great irritability of the retina, which is gradually decreased by fatigue.

4. *The illumination of the surroundings of the observed object.*—A light upon a dark background appears lighter than upon a bright background (simultaneous contrast). This contrast is greatest at the limit between the light and

the dark, e.g. a white object on a dark background appears to be surrounded by a very dark border.

Irradiation.—Light objects upon a dark background appear larger than they really are. This is due either to the fact that the stimulation of a portion of the retina radiates to the neighboring parts or that, because of imperfect accommodation, the image of the light object is enlarged by circles of diffusion.

B. **Quality of the visual sensation.**—The retina is stimulated only by rays whose wave lengths lie between 0.69μ and 0.39μ. These visible rays are found in daylight.

Strictly speaking, not all the visible rays are present in daylight, for those corresponding to the Fraunhofer lines are not present.

The sensation produced by daylight is **white.** A white color of lower intensity is called **gray.** Objects which send out no rays capable of stimulating the retina appear **black.**

The visible rays are the more refractive the shorter their wave length. When the various rays are separated by passing the light through a prism, it is observed that they produce various visual sensations, called **color sensations.**

The sensation of

Red	is	produced	by	rays	of	$0.69\ \mu$ wave-length.
Orange	"	"	"	"	"	0.64 " "
Yellow	"	"	"	"	"	0.59 " "
Green	"	"	"	"	"	0.53 " "
Blue	"	"	"	"	"	0.46 " "
Violet	"	"	"	"	"	0.39 " "

The sensations of color are produced by the simple or homogeneous rays only in medium intensity. All rays which in medium intensity appear colored are colorless in very strong or weak intensity. If the intensity of homogeneous rays is decreased, the relative brightness is changed. The spectral red is brighter in medium intensity and darker in lesser intensity than the blue. This, however, can be observed only by the eye adapted to dim vision.

Mixed colors are produced by the simultaneous action of rays of various wave lengths upon the retina. Of the mixed colors one, i.e. purple, is not found in the spectrum. It is produced by mixing red and violet. The mixed colors appear whiter, less saturated, than the corresponding spectral colors. For example, spectral red and yellow mixed form an orange color which appears whiter than the orange of the spectrum.

Complementary colors are two colors which by mixing give the sensation of white. The following are pairs of complementary colors: red and greenish blue, orange and blue, green and indigo blue, greenish yellow and violet.

The **theories of color** reduce the many color sensations to the simultaneous but unequal stimulation of a few primary colors. The **Young-Helmholtz theory** assumes three primary color sensations—red, green, and blue, which by the action of a light are always stimulated simultaneously but unequally by the individual homogeneous rays. By the mixing of the various primary colors, the different color sensations are produced. If the three color sensations are equally stimulated, the sensation of white is produced.

Recently the idea has been advanced that only the cones of the retina are the apparatus for the color sensations, and that with these are connected three classes of nerves corresponding to the three primary color sensations. The rods are supposed to be sensitive only to white light of low intensity, and this sensation is brought about by the decomposition of the visual purple. According to this view, only the rods are stimulated by light of very low intensity, which therefore appears colorless, while such light is not able to stimulate the cones. In dim light we therefore see chiefly with the rods, in bright light with the cones.

Hering's theory of opposite colors assumes six primary color-sensations, which are classified into three groups of two sensations each:

1. White and black; 2. Red and green: 3. Blue and yellow. For each group a visual substance is assumed by whose changes sensations are produced. The changes of the substance may be of two kinds; the one kind produces one sensation, the other, opposite in character to the first, produces the other sensation. Of the two opposite processes, one is supposed to be the dissimilation, the other the assimilation, of the visual substance.

The retina is sensitive to colors only in its central portion. As we proceed to the periphery the power of discerning colors decreases. The outermost parts of the retina are color-blind.

Besides the color-blindness in the peripheral region of the retina, pathological color-blindness of the whole retina occurs.

This color-blindness may be:

1. Total, in which all color sensations are absent, all objects appearing colorless.
2. Partial.

Partially color-blind persons have but two kinds of color sensations:

(*a*) The more general form, the red-green blindness, in which only blue and yellow give rise to sensations, while red and green appear colorless.

(*b*) The blue-yellow blindness, in which only the red and green give rise to sensations, while blue and yellow appear colorless.

The red-green blind can be divided into two groups which are separated from each other by typical differences in the lack of color sensations. For the one red or bluish green are colorless, for the other purple-red and green.

Color-blindness has been explained either by the lack of certain primary sensations or by changes in the irritability of the elements of color sensations.

The negative after-image of a color sensation has the color complementary to the original color. A colored light upon a colorless background calls forth a colored simultaneous contrast, in which the background has the color complementary to that of the colored light.

3. VISUAL PERCEPTION

I. Monocular vision.

Space sensation of the retina.—We are able to see objects of the outer world clearly in their position because we can distinguish different luminous object points. The distinguishing of several object points is rendered possible by the mosaic construction of the retina from elements each of which produces a separate sensation when it is stimulated by light from a luminous point. In the fovea centralis each cone may be regarded as such an element, but at the periphery of the retina several of the rods and cones collectively form one element.

From experience we seek the source of the light which has stimulated a sensational element, in the line drawn from this element through the nodal point outward (see pages 258 and 261). *Hence by vision with one eye we are able to tell the direction in which the object lies.*

Two separate object points are seen distinctly when their image points fall upon two sensational elements separated by at least one other element.

Acuteness of vision is the power by which two luminous points can be distinctly seen. The acuteness of vision is the greater the smaller the diameter of the sensational element or the smaller "the smallest visual angle," when the luminous points can still be seen as distinct points. The **visual angle** is the angle which the direction rays from the luminous points form with each other.

We can discriminate between **direct** and **indirect** vision. A point seen by direct vision is called the **fixed object point.** We see less distinctly by indirect than by direct vision.

The **fovea centralis** functions in direct vision. It has the greatest acuteness of vision, and by means of it we can, under favorable circumstances, distinguish two luminous points which form a visual angle of 40 seconds. This corresponds to a diameter of 3μ of the sensational element (a little more than the diameter of a cone in the fovea). The peripheral portions of the retina function in indirect vision and have less acuteness of vision.

Oculists regard five minutes as normally the smallest visual angle for the fovea, which is true for the method generally in vogue for determining acuteness of vision (reading of letter).

The direction ray drawn through the fovea is called the **visual axis** or line of fixation (see Fig. 28, *G G'*); in it lies the luminous point which we fix upon in seeing. This line does not coincide with the optical axis, but its anterior end is a little inward from the optical axis. The angle formed by these two lines is called the "angle α" and is about 7°.

The **visual field** is the field in which all the luminous points seen by the stationary eye seem to lie. The visual field therefore includes all the directions in which the stationary eye can see objects. Its extent is indicated by the angles which the lines drawn from the limits of the visual field through the nodal point form with the visual axis. The extent of the visual field is outward 70–90°, inward

50–60°, upward 45–55°, downward 65–70°. The perimeter is used in determining the field.

II. **Movements of the eyes.**

1. **Movement of one eye.**—(*a*) *General observations.*—The external eye muscles turn the eyeball about a point lying on the optical axis, 13.557 mm behind the cornea. The eye and its socket form a ball-and-socket joint (see page 202).

The monocular field of vision [Blickfeld] is the field which includes all the luminous points that can be seen by the moving eye, the head being held quiet.

Primary position is the position of the eye when a person looks straight forward into the distance, the head being held erect. In the primary position the visual axis is horizontal and parallel to the median plane of the body. For any given position of the visual line it is mechanically possible that the eye can still assume many positions because of its

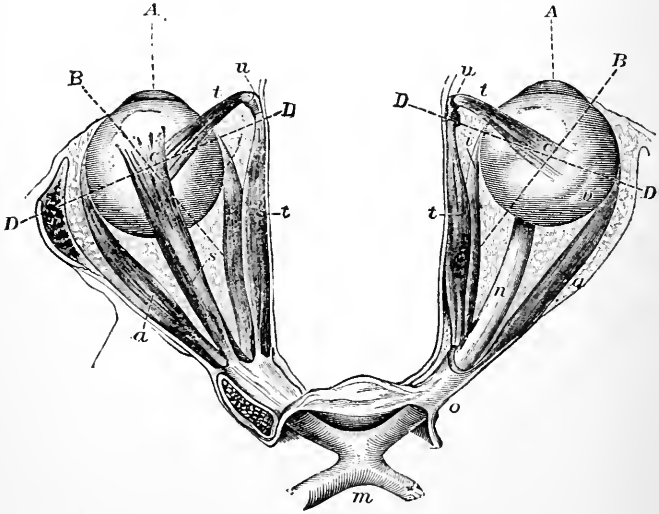

FIG. 35.—MUSCLE AND AXES OF ROTATION OF THE EYE. (After Helmholtz.)

a. rectus externus; *s*, rectus superior; *i*. rectus internus; *t*, obliquus superior; *u*, trochlea; *A*, optical axis; *DD*, axis of rotation of the rectus superior and inferior; *B*, axis of rotation of the obliquus superior and inferior; *v*, insertion of obliquus inferior.

ability to turn around the visual line as an axis. In reality such a turning does not take place, but for each position of the visual line the whole eye has a definite position. This is due to the peculiar coördination of the innervation of the eye muscles. The position of the eye for any given position of the visual axis is such as if it moved from the primary to the new position by rotating around an axis perpendicular to the visual axis in the primary and the new position.

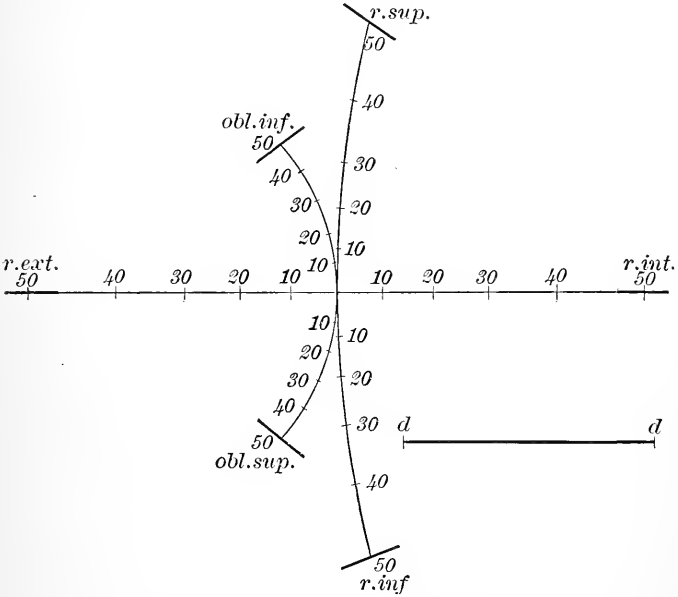

Fig. 36.—Action of the Eye Muscles.

Lines described by the line of vision in the visual field when the eyeball is turned from its primary position by some muscle of the eye. The movements of the point of vision [Blickpunkt] corresponding to the angle of rotation are indicated on the lines in degrees. The distance of the plane of the paper from the point of rotation of the eye equals the line *dd*. The position which the horizontal meridian in a primary position assumes is indicated at the end of each line.

(*b*) *Action of the individual muscles* (see Figs. 35 and 36).—The change in position of the eye may be stated as follows:

1. Change in the position of the anterior surface of the

cornea, i.e. raising, lowering, adduction (to nasal side) and abduction (to malar side).

2. Deviation of the perpendicular meridian of the cornea in the primary position from the perpendicular (wheel movement inward when the upper part of the meridian is bent toward the median plane; wheel movement outward when this part is bent away from the median plane).

The eye is turned from the primary position:

1. By the rectus externus; abduction.
2. By the rectus internus; adduction.
3. By the rectus superior; upward, adduction and wheel movement inward.
4. By the rectus inferior; downward, adduction and wheel movement outward.
5. By the obliquus inferior; upward, abduction and wheel movement outward.
6. By the obliquus superior; downward, abduction and wheel movement inward.

The action of these muscles is illustrated in Fig. 36.

(*c*) *Combined action of the muscles of one eye.*—The rectus superior and obliquus inferior are always simultaneously innervated (from a coördination centre); also the rectus inferior and obliquus superior.

The *secondary position*, i.e. abduction, adduction, raising, lowering, are not accompanied by wheel movements. By simple raising and lowering, the adduction and wheel movement produced by one of the active muscles is destroyed by the opposite action of the other muscle. All other movements (*tertiary position*) are associated with wheel movements. This wheel movement takes place:

1. Outward (*o. inf.*) by raising (*r. sup.*) and abduction (*r. ext.*);
2. Inward (*r. sup.*) by raising (*o. inf.*) and adduction (*r. int.*);
3. Inward (*o. sup.*) by lowering (*r. inf.*) and abduction (*r. ext.*);

4. Outward (*r. inf.*) by lowering (*o. sup.*) and adduction (*r. int.*).

2. **Combined action of the muscles of both eyes.**—The two eyes are moved simultaneously. They are innervated from a common centre. The movements are as follows:

1. *Rect. sup.* and *obl. inf.* on both sides = raising of both eyes;
2. *Rect. inf.* and *obl. sup.* on both sides = lowering of both eyes;
3. The left *rect. int.* and right *rect. ext.* = movement of both eyes to the right;
4. The left *rect. ext.* and right *rect. int.* = movement of both eyes to the left.
5. *Rect. int.* on both sides = convergence;
6. *Rect. ext.* on both sides = divergence.

With the convergence is associated accommodation and constriction of pupil.

Binocular point of vision is the point in space on which both eyes are fixed and in which, therefore, the two visual axes meet.

Binocular field of vision is the field which includes all the object points which can be perceived by the two eyes when the head is held stationary.

The monocular fields of the two eyes nearly but not altogether cover each other. But the binocular field of vision is much smaller than that part of the monocular fields common to both eyes, for the two visual axes cannot be directed simultaneously upon a point upon which each visual axis can independently be directed.

III. Binocular vision.

1. **Single vision with both eyes** [diplopia].—Those objects in the outer world whose images fall on identical points of both retinæ are seen as single objects. Identical points of the two retinæ are therefore such points whose simultaneous stimulation by a luminous object gives rise to a single sensation.

A pair of identical points are, for example, the two foveæ centralis, and also two points on both retinæ equidistant and located in the same direction from the foveæ centralis (see Fig. 37).

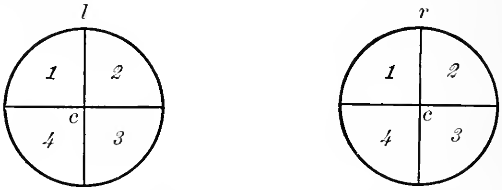

FIG. 37.—IDENTICAL POINTS ON THE RETINÆ.

The right (*r*) and the left (*l*) retina are divided into the quadrants 1, 2, 3, and 4 by the perpendicular and horizontal lines drawn through the foveæ *c*. If the points *c* and the corresponding dividing lines are placed over each other, every point of one retina will be covered by its identical point of the other retina.

A luminous point whose image does not fall on identical points of the retinæ is seen double.

If identical points of the retinæ are stimulated by different objects, the two objects are not seen simultaneously, but first one and then the other is seen, according to whether the attention is first fixed upon the one or upon the other. This is called the *struggle of the two fields of vision* [Wettstreit der Sehfelder].

For a given position of the eyes the field in which all points are seen as single points is called the **horopter.**

To find the horopter, draw lines from a pair of identical points through the nodal points; the point where these two lines cross is seen as a single point. All the points thus found form the horopter for this given position of the eyes.

2. **Perception of solidity.**—By binocular vision we can see an object from two different directions. Hence the position of the object is where the two visual lines cut each other. If a solid object is viewed with both eyes, two distinct images of the object are formed upon the retinæ because the two eyes view the object from two different points of view. Hence the images falling upon identical points of the retinæ are not the same. Consequently only a part of the points of the observed object appear as single points; the others are seen double. This gives us the impression of a solid body.

If we present to each eye, from its own standpoint, a picture of the same body, the eyes see the pictured object as a solid body. The instrument by which this is done is called the **stereoscope.**

The judgment concerning the distance and the direction of an object is based chiefly upon the degree of contraction which the external eye muscles and the muscle of accommodation undergo in fixing the gaze upon the object. The judgment of the size of the object is formed by comparison with an object of known size, correction being made for the distance of the object. Errors made in judging the distance and direction of objects are called optical illusions.

1. *The protective organs of the eye.*—By the *closing of the eyelid* the eyeball is protected from injurious external influences. This is accomplished by the orbicularis palpebrarum, which is innervated by the facial. The closing may be a voluntary or a reflex act. The reflex closing is brought about by too strong stimulation of the retina (blinking) or by the stimulation of the cornea and conjunctiva.

The surface of the eye is kept moist and clean by the *tears.* The tears flow from the efferent duct of the lachrymal gland into the conjunctival sac and are distributed by the closing of the lid and by the movements of the eye. In this manner the closing of the lid keeps the cornea moist and clean. From the conjunctival sac the tears flow through the nasal duct into the nose.

The Meibomian glands in the eyelids are sebaceous glands whose secretion oils the borders of the lids. This prevents the flowing of the tears over the lids.

2. *Blood and lymph circulation in the eye.*—The blood enters the eye:

(1) By the central artery of the retina, which supplies the retina with blood.

(2) By the ciliary arteries which pass to the choroid.

Communications exist between the branches of the vessels of the retina and of the choroid, especially near the entrance of the optic nerve.

The blood leaves the eye:

(1) By the central vein of the retina (from the retina).

(2) By the vorticosæ veins (from the choroid).

The *aqueous humor* may be regarded as lymph which, in the posterior chamber of the eye, is secreted by the ciliary processes and the posterior surface of the iris. The discharge of the aqueous humor takes place in the anterior chamber in the angle between the sclerotic and the iris. The lymph is here absorbed into a venous vessel, the canal of Schlemm (*s*, Fig. 30). There are no special lymph vessels in the eye.

The *vitreous humor* is a jelly-like tissue, consisting of an alkaline fluid inclosed in a delicate membrane. This membrane is composed of collagen; the fluid contains 1.3% solids, including traces of albumin and globulin, also a proteid substance called mucoid, and finally 9% salts. The lens is composed of fibres which may be regarded as cells; these contain about 36% solids, chiefly a globulin-like proteid (35%).

CHAPTER XXII

THE EAR

THE ear contains the sense organ of hearing and the organ for perceiving the positions and movements of the head.

1. THE AUDITORY ORGAN

The adequate stimuli for the auditory organ are the vibrations of solid, liquid, or gaseous bodies, called sound waves, because by their action upon the auditory organ they give rise to the sensation of sound. These vibrations are usually carried to the ear by air. But the vibrations can also be carried to the ear through the bones of the head, as when

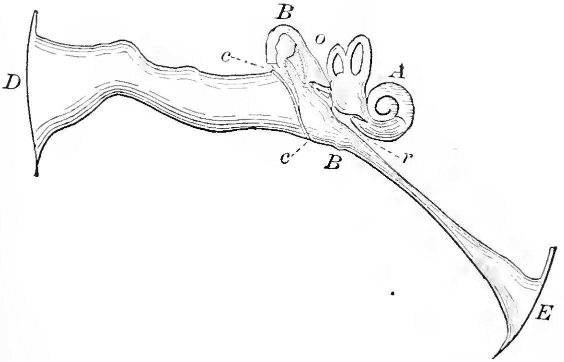

FIG. 38.—DIAGRAMMATIC VIEW OF THE ORGANS OF THE EAR. (After Helmholtz.)

D, external auditory canal; *cc*, membrana tympani; *BB*, cavity of the tympanum with the auditory ossicles; *o*, fenestra ovalis; *r*, fenestra rotunda; *A*, cochlea; *E*, Eustachian tube.

the source of the vibrations, e.g. a tuning-fork, is brought into contact with them.

1. **Conduction of sound in the ear to the sensory apparatus** (see Fig. 38).

(*a*) **The propagation of sound in the external ear.**—The external auditory canal (*D*, Fig. 38) serves as a funnel which by reflection from its wall gathers the sound vibrations and conducts them undiminished to the ear-drum (*cc*) which closes the bottom of the canal. The auricle or pinna of the ear is the rudiment of the elongation of this funnel-like passage. The membrana tympani is set in vibration by the vibrations which have been conducted to it.

(*b*) **The propagation of sound in the middle ear.**—The middle ear or tympanum (*BB*, Fig. 38) is a cavity in the petrous bone and contains air. Its outer wall is formed by the drum, its inner wall by a bone in which are two apertures closed by membranes, the round and oval fenestræ.

The membrana tympani is connected with the fenestra ovalis by the auditory ossicles, which convey the vibrations of the ear-drum to the membrane of the fenestra ovalis. The auditory ossicles are the hammer, anvil, and stirrup (stapes), see Fig. 39.

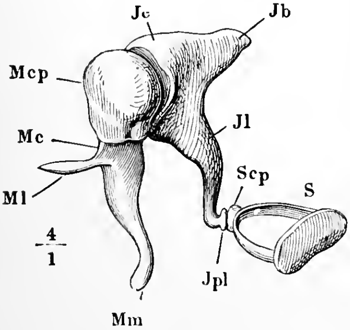

Fig. 39.—Auditory Ossicles.

Mm, manubrium of malleus; *Mcp*, head, and *Ml*, long process, of the hammer; *Jc*, incus, or anvil-bone; *Jb*, short, and *Jl*, long, process of the anvil; *S*, stapes.

The manubrium of the hammer, *Mm*, is united with the ear-drum, lying in its upper vertical radius. From the neck of the hammer proceed two ligaments to the walls of the tympanum which allow the hammer to move around on an approximately horizontal sagittal axis. The head of the hammer, *Mcp*, is united to the anvil by a joint which allows of but little movement, and this movement is largely prevented when the manubrium is moved inward by a coglike process.

The anvil, *Jc*, has two processes, one behind, *Jb*, which is movably connected with the posterior wall of the tympanic cavity, and a lower process, *Jl*, whose point is connected by means of a sesamoid bone with the stapes (stirrup) *S*. The base (foot) of the stirrup is united with the membrane of the fenestra ovalis (*o*, Fig. 38).

The auditory ossicles form a lever turning about the axis of the hammer, one of whose arms is the manubrium of the hammer, while the other arm extends from the axis to the point of the lower process of the anvil and, through the stirrup, is connected with the membrane of the fenestra ovalis. If the drum vibrates transversely to and fro, its movements are carried by the lever to the membrane of the fenestra ovalis.

The sound-conducting apparatus of the middle ear is so constructed that it is evenly set in sympathetic vibration by sound vibrations of various lengths. A free and uniformly stretched membrane gives out, when it is struck, a certain note whose pitch depends upon the size and tension of the membrane. Such a membrane is set in especially strong vibration when in its neighborhood a note having the same pitch as that produced by the membrane is sounded. The drum of the ear has no definite note of its own because of its complicated structure (funnel-shaped, being pulled inward by the manubrium of the hammer). By this its tension in different directions is not the same and therefore it can have no definite note of its own. It can therefore be set into sympathetic vibration to the same extent by many different notes.

The sound-conduction apparatus of the ear is provided with a very effective damper, so that no perceptible after-vibrations occur when the notes producing the vibrations have ceased.

The following muscles are inserted on the auditory ossicles:

(1) *Tensor tympani*, which lies in a bony canal extending parallel with the Eustachian tube. It is united to the

manubrium of the hammer by a tendon bending around a bony process. By its contraction the manubrium is bent inward and thus stretches the drum. It is innervated by the trigeminus.

(2) *Stapedius*, whose tendon is attached posteriorly to the head of the stapes. It is innervated by the facial.

The functions of these muscles are not fully understood. They probably exist for the purpose of rendering the conducting apparatus more fixed when a strong sound meets the ear in order that the vibrations may be made weaker and thus prevent the auditory nerve from being too strongly stimulated. By means of the tensor tympani the tension of the membrana tympani can be accommodated to very high notes.

The *Eustachian tube*, a narrow canal (*E*, Fig. 38), passes from the floor of the tympanic cavity forward and downward and connects the middle ear with the pharynx. The tympanic cavity and the Eustachian tube are covered with mucous membrane. The opening of the Eustachian tube into the pharynx is generally closed by a fold in the mucous membranes. During deglutition it is opened for a brief period by the contraction of the tensor muscle and the levator palati mollis. By the opening of the tube the pressure of the external air and the air in the inner ear are equalized, which is absolutely necessary for the normal conduction of sound into the middle ear. If the tube is closed by catarrhal swelling of its mucous membrane, disturbances in hearing result. The mucous membrane of the tube is lined with cilia which move the mucus toward the pharynx.

(*c*) **The conduction of sound in the internal ear.**—The internal ear, or labyrinth, is a cavity in the petrous bone and is filled with a fluid. In the outer wall of the cavity are the fenestræ rotundis and ovalis.

The anterior part of the internal ear is the cochlea (*A*, Fig. 38), a spirally wound canal of two and one-half turns, divided into two parts by a bony plate. As the bony plate is interrupted in the cupola, the passages of the canal communicate at this place (helicotrema). One of the passages, the scala vestibuli, opens at the base of the cochlea into the median part of the labyrinth, the vestibule, which is separated from the middle ear by the fenestra ovalis. The other passage of the cochlea, the scala tympani, ends, at the base, in the fenestra rotundis (compare Figs. 40 and 41).

In the labyrinth, therefore, the passage from the fenestra ovalis to the fenestra rotundis goes through the canals of the cochlea. By the vibrations of the membranes of the fenestra ovalis the water in the labyrinth is caused to vibrate and presumably that in the cochlea, because the passage from the fenestra ovalis to the other yielding place of the labyrinth wall (the membrane of the fenestra rotundis) passes through the cochlea. The movement of the water in the labyrinth is rendered possible by the existence of this second flexible part [membrane of the fenestra rotundis]. The partition in the canal of the cochlea is partly membranous, and the vibrations of the water of the labyrinth are conveyed to this membrane. This membrane contains the sensory apparatus which is stimulated by the vibrations.

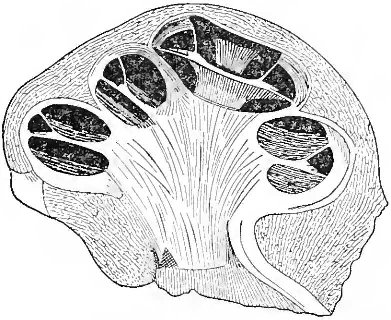

Fig. 40.—Cross-section of the Cochlea.

2. **The sound-sensations.**

(*a*) **The apparatus for the auditory sensations** (Fig. 41).—The septum of the cochlea canals consists of:

1. The lamina spiralis ossea (*lso*), which extends from the axis of the cochlea (modiolus) into the lumen of the cochlea canal.

2. The lamina spiralis membranacea forms the continuation of the lamina ossea and extends to the outer wall of the cochlea. It is formed by the basal membrane (*b*), composed of parallel transverse fibres, and contains the apparatus for auditory sensations, i.e. organs of Corti (*Co*), placed upon the basal membrane. Each organ of Corti consists of:

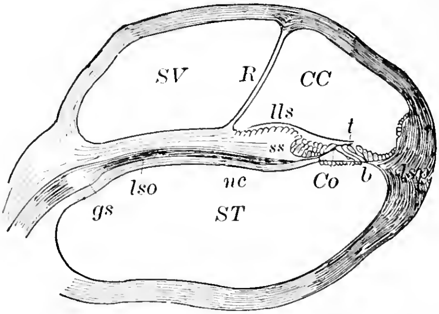

FIG. 41.—CROSS-SECTION OF ONE OF THE COILS OF THE COCHLEA.

(After Rauber.)

SV, scala vestibuli; *ST*, scala tympani; *CC*, canalis cochlea; *lso*, lamina spiralis ossea; *b*, membrana basilaris; from *lls* to *lsp*, lamina spiralis membranacea; *Co*, organ of Corti; *nc*, nerve bundle; *R*, membrane of Reissner.

1. The pillars of Corti (*CC*, Fig. 42), i.e. two pillars bent in the form of the letter *S*, resting on the membrana basilaris. One is called the inner, the other the outer, pillar, and the two unite at the top.

2. The cells of Corti or hair cells (*h*), cylindrical cells of which one is placed internal and three or four external to the pillars. At their free surface they are provided with small hairs which project through perforations of a supporting membrane, the membrana reticularis. Above this is placed another membrane, the membrana tectoria (*Mt*).

The membrane of Reissner (*R*, Fig. 41), which proceeds obliquely upward from the lamina spiralis ossea and unites with the upper wall of the cochlear canal, separates the canalis cochleæ (*C C*, Fig. 41), in which the organs of Corti are placed, from the scala vestibuli. The canalis cochleæ ends in a blind sac in the cupola; at the base it passes into the inner chamber of the membranous labyrinth.

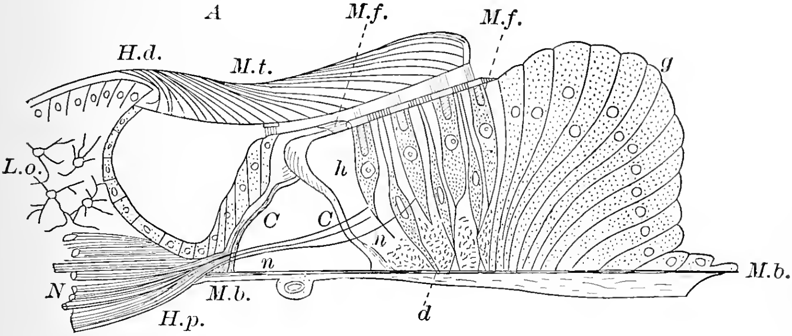

Fig. 42.—Cross-section of the Lamina Spiralis Membranacea.

Lo, lamina spiralis ossea; *N*, cochlear nerve; *n n*, nerve fibres; *C C*, pillars of Corti; *Mt.* membrana tectoria; *Mb*, membrana basilaris; *h*, hair cells; *Mf*, membrana reticularis; *d*, Deiter's cells; *Hd*, habenula denticulata; *Hp*, habenula perforata.

The membranous labyrinth (see Fig. 43) is a membranous covering of the vestibule and the posterior part of the labyrinth, the semicircular canals (see page 294). In the vestibule the membranous labyrinth is divided by constriction into two parts, the anterior sacculus and the posterior utriclus.

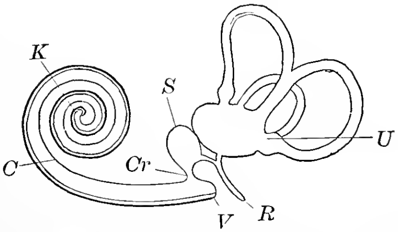

Fig. 43.—The Membranous Labyrinth (Diagrammatic).

U, utriculus with the semicircular canals; *S*, sacculus; *C*, cochlea; *K*, cupola; *v*, cul-de-sac of the vestibule; *Cr*, canalis reuniens; *R*, ductus endolymphaticus.

The membranous labyrinth is filled by the endolymph, while the space between the membranous and the bony labyrinth is filled with the perilymph.

The auditory nerve divides into two branches:

1. The *cochlear nerve*, the real nerve of hearing, enters at the axis of the cochlea and in the lamina spiralis ossea spreads out its fibres like a fan. Its fibres finally unite with the hair cells of the organ of Corti (see Fig. 42, *N*, *n n*).

2. The *vestibular nerve* (see page 295).

(*b*) **The auditory sensation.**—The membrana basilaris is set in vibration by the perilymph. By this the cells of Corti are probably mechanically stimulated and thus the auditory sensation is produced.

Auditory sensations may be classified as tones and noises. The **tones** (musical) are produced by regular vibrations and may be distinguished by pitch and timbre. The **pitch** of a musical tone depends upon its number of vibrations. The greater the number of vibrations per second the higher the pitch. The audible tones lie between those having 19 and 40,000 vibrations per second ($11\frac{1}{2}$ octaves). The tones used in music lie between those having 33 (contra *C*) and 4000 (a'''') vibrations.

The time which the tone must act in order to be heard depends upon the pitch of the tone. Those of higher pitch need less time than the lower tones. In order to judge of the pitch of a tone, at least 16 single vibrations must strike the ear. If less than 16 vibrations strike the ear, we cannot accurately judge of the pitch. Auditory sensations, however, are still produced if but two single vibrations reach the ear.

The accuracy of determining the pitch of a tone varies much in different individuals. It depends upon ability and practice. Trained musicians can still discriminate between the pitch of two tones having 1000 and 1001 vibrations (musicians call this $\frac{1}{128}$ of a whole note).

The perception of tones of different pitch has been explained by Helmholtz by the resonance theory as follows:

The membrana basilaris decreases in width as we proceed from the cupola to the base of the cochlea (see Fig. 44). As the membrane is composed of transverse fibres, its tension in this direction is greater than that in the longitudinal direction, and therefore as a resonator it acts like the strings of a piano. If one sings a certain note near an open piano, the string which has the same number of vibrations as the note sung is set into sympathetic vibration, the other strings remaining quiet. In the same manner if a note strikes the membrana basilaris, that segment of the membrane whose number of vibrations correspond to that of the note will be made to vibrate. Each segment which can vibrate by itself stimulates the cells of Corti found on it, and therefore only certain fibres of the auditory nerve are stimulated. The corresponding cerebral cells, because of their specific energy, perceive tones of certain pitch.

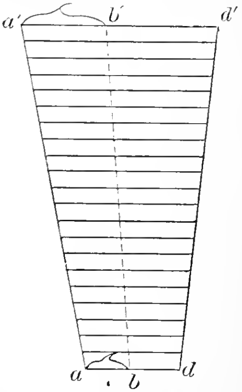

Fig. 44.—Diagram of the Membrana Basilaris, unrolled. *a'd'*, width of membrane at the cupola; *ad*, width at the base of the cochlea; *a'b'* and *ab*, the width of the pillars of Corti.

The quality or **timbre** of tones. Most tones are not simple tones but are accompanied by overtones which, as a rule, are higher than the fundamental tone. Each tone, in a mixture of tones, gives rise to a sensation, hence several sensations are produced which we call the quality, or timbre. The timbre of one and the same fundamental tone varies with the number and strength of the accompanying overtones.

If two tones whose number of vibrations have a simple ratio (1 : 2, 2 : 3, 3 : 4, 4 : 5) are sounded simultaneously, the resulting sound is agreeable—consonance. The simultaneous sounding of two tones whose number of vibrations are not in a simple ratio produces a disagreeable sound—dissonance.

Frequently we are able to analyze a mixed sound into its components; we are able, for example, to distinguish the parts played by the different instruments of an orchestra.

If two tones differing but little in their number of vibrations are sounded simultaneously in such a way that at one time the crests of both waves correspond and at another the crest of one corresponds to the trough of the other, **beats** are heard, i.e. periodic increase and decrease in the auditory sensation. Beats occurring more frequently than 32 per second cause an auditory sensation called beat-tone.

These beat-tones are a purely subjective phenomenon; they cannot, like other tones of a mixed sound, be demonstrated by the resonator, for they do not affect the resonator. Hence the production of auditory sensations by such tones cannot be explained by Helmholtz's theory of resonants.

The sensations of noises are produced by irregular vibrations in which now one, now another portion of the basilar membrane is set in vibration.

In the sense of hearing, as in sight, there are certain phenomena produced by the rise and fall of the auditory sensation, as also the phenomenon of fatigue.

Two sounds following each other are still heard as separate sounds if the interval between them is not less than 0.1 second.

The judgment of the direction and distance from which a sound comes is very imperfect. Both ears serve in judging of the direction of the sound, it coming from the direction towards which the ear most stimulated is turned.

2. THE SENSE ORGANS FOR PERCEIVING THE POSITION AND MOVEMENTS OF THE HEAD

The posterior part of the bony labyrinth is composed of the three semicircular canals, which are bony canals bent in the form of a C. They originate and end at the vestibule. Each canal has at both ends a dilation (ampulla). The planes of the superior-anterior canal lie in the vertical longitudinal plane; that of the inferior posterior in the vertical transverse; that of the lateral in the horizontal plane. Hence the three planes of the semicircular canals are perpendicular to each other. The bony canals surround the membranous labyrinth (see page 291).

The thin walls of the membranous labyrinth are thickened in the utriculus and in the sacculus (maculæ acusticæ utriculi et sacculi) and in the ampullæ (cristæ acusticæ).

The epithelial cells covering the inner walls of the membranous labyrinth form hair cells in the maculæ and cristæ whose hairs extend into the cavity of the membranous labyrinth. These hair cells are neuro-epithelial cells in which the fibres of the auditory nerve end. A branch of the cochlear nerve goes to the macula sacculi, while the vestibular nerve goes to the macula utriculi and the cristæ.

Upon both maculæ lies a thin jelly-like membrane, the membrane of the otoliths; upon the surface of this membrane lie the otoliths (consisting of calcium carbonate).

The fibres of the auditory nerve to this part of the labyrinth are, according to the prevalent theory, not nerves of hearing, but serve to perceive the position and movements of the head. Their neuro-epithelial cells are supposed to be mechanically stimulated either by the pull which the otoliths exert because of their weight or by the hydrostatic pressure of the endolymph, which varies with the different positions of the head. They may also be stimulated by the movements of the endolymph brought about by movements of the head.

Reflexly coördinated movements for the maintenance of the normal position of the head and the equilibrium of the body are in part called forth by impulses from the semicircular canals and the otolith organs. The compensatory movements of the eye (page 242) are also called forth by the stimulations from the semicircular canals. Destruction of the semicircular canals in animals is followed by disturbances in the normal position and movements of the head and of the whole body (forced positions and movements). It is also followed by diminution of the energy and tonus of skeletal muscles and disturbances in muscular sense.

CHAPTER XXIII

SMELL

THE organ of smell lies in the regio olfactoria of the nasal mucous membrane (upper part of the septum nasi, upper meatus, upper part of the middle meatus). It is composed of rods which lie between the epithelial cells. These rods end externally in delicate hairs (Figs. 45 and 46); internally

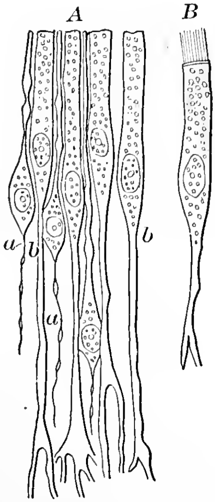

FIG. 45.
(After M. Schultze.)

A, epithelium of the mucous membranes of the olfactory region; *a a*, olfactory cells; *b b*, supporting cells; *B*, ciliated epithelial cell from the regio olfactoria.

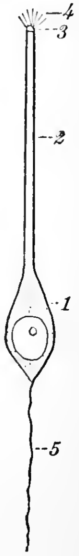

FIG. 46.—OLFACTORY CELL OF MAN. (After v. Brunn.)

1, cell-body with its nucleus; 2, peripheral rod, with 3, its extremity, furnished with hairs, 4; 5, central filament (beginning of an olfactory fibre).

they are connected with the olfactory cells whose axis cylinders pass through the cribriform plate to the bulbus olfactorius (see page 250).

Adequate stimuli for the organ of smell are gases carried through the nose by inspiration and diffused in the regio olfactoria.

The liminal intensity of many substances is very small; 1 millionth of 1 milligram of musk or butyric acid in 1 litre of air can be detected by the sense of smell, while of mercaptan still less is necessary.

The organ of smell is very soon fatigued.

The sensations of smell have many different qualities which have not yet been classified. Mixed odors are produced by the action of two or more odorous substances. Some odors are able to neutralize each other.

Corrosive gases cause tactile sensations in the nasal mucous membrane which may be accompanied by sensations of smell.

CHAPTER XXIV

TASTE

THE organ of taste is composed of taste goblets which are goblet-shaped structures with an aperture towards the buccal cavity and contains spindle-shaped cells (see Figs. 47 and 48). The branches of the nerves supplying these structures end between these cells. Taste-goblets are found in the epithelium of the circumvallate, foliate, and fungiformes papillæ of the tongue, as also in the soft palate and the posterior pillars of the fauces. The nerve of taste is the *glossopharyngeal*, whose fibres reach the taste organs in part directly and in part through the Jacobson's anastomose and lingual nerve (see page 252).

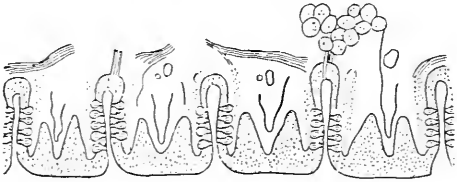

FIG. 47.—CROSS-SECTION OF THE TASTE PAPILLÆ OF THE TONGUE, IN WHICH LIE THE TASTE-BUDS.

Adequate stimuli for the organs of taste are liquid and dissolved substances, or at least such as are soluble in saliva.

The intensity of the taste sensation depends upon the concentration of the solution. The liminal intensity is different for the various tastable substances. The concentration necessary for some substances is seen in the following table:

Aloe	1 : 900,000
Sulphuric acid	1 : 100,000
Sodium chloride	1 : 426
Cane-sugar	1 : 100

The intensity of taste sensation is greater the greater the surface of mucous membrane affected. The taste sensation is favored by pressing the tongue against the palate.

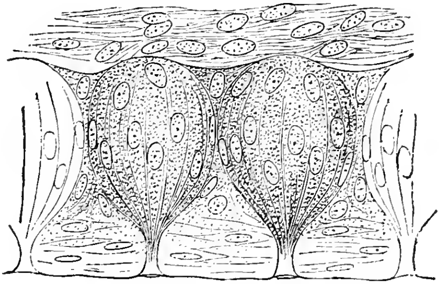

FIG. 48.—TASTE-BUDS HIGHLY MAGNIFIED.

The best temperatures for taste lie between 10° and 35° C.

Hot or cold water temporarily inhibits taste.

There are four qualities of taste sensations:

1. Sweet, caused by sugar, saccharin, and certain alcohols.
2. Bitter, caused by alkaloids.
3. Salt, caused by neutral salts.
4. Sour, caused by acids.

A solution tastes the more sour the greater the number of hydrogen atoms replaceable by metals contained in the unit of volume. Many authors consider the alkaline and metallic taste as the fifth and sixth qualities of taste sensation.

There are also mixed taste sensations of two or more taste qualities.

The sensations of taste are often accompanied by tactile sensations (astringent taste) and by sensations of smell (bouquet of wines).

CHAPTER XXV

CUTANEOUS SENSATIONS

The sense organs here dealt with are chiefly located in the outer skin, but are also found in some parts of the mucous membranes bordering on the skin, for example that of the jaws, mouth, nose, conjunctiva, anus, vagina, and urethra. One kind of these sense organs is present not only in the skin and mucous membrane, but in all organs of the body—the sense organs of pain.

1. **The organs of the tactile sensation.**—The cutaneous sense organs are composed of the endings of sensory nerves in the skin. These endings may be classified as follows:

1. *Free nerve endings* between the epithelial cells.

2. The *nerve-wreath of hairs* which surround the hair-bulb just beneath the opening of the sebaceous glands.

3. *Tactile cells* are found in the deepest layers of the epidermis and the neighboring layers of the cutis vera in which are found non-medullated nerve fibres.

4. *End-bulbs.* These are spherical or oval bodies composed of a connective-tissue capsule and a granular jelly-like medulla—in which the nerve fibres end. In this class belong:

(*a*) The *tactile corpuscles of Meissner*, elliptical, transversely striated structures. The nerve endings in these corpuscles form a complicated network.

(*b*) The *end-bulbs of Krause*, cylindrical structures in which the axis cylinders are straight and end free.

(*c*) The *genital corpuscles*, oval, unstriated bodies much similar to the tactile corpuscles.

(*d*) The Vater-Pacini corpuscles, whose capsule is composed of many concentric lamellæ.

2. **Qualities of cutaneous sensations.**—There are four qualities of cutaneous sensations, viz., touch, heat, cold, and pain.

These various qualities are located in various parts in the skin. There are portions whose stimulation calls forth tactile sensations only, so-called tactile or touch points; we can also discriminate warmth, cold, and pain points.

These four kinds of points are not evenly distributed over the whole body. Some of them are lacking in certain regions of the body, e.g. the central part of the cornea has only pain points, while its peripheral portion is provided with pain and cold points. The glans penis contains no tactile points; a part of the mucous membrane of the cheek lacks pain points.

In those regions of the body where the four kinds of points are all found, the pain points are generally most numerous, then follow the tactile and cold points, while the warm points are least numerous.

(*a*) **Tactile sensation.**—The adequate stimulus for the tactile sense organs is the pressure exerted upon the skin. Concerning the nature of the stimulation of nerve endings by pressure nothing is known. Stimulation by pressure occurs only at the boundary of the portion of the skin pressed, where, therefore, a fall in pressure exists.

For example, if a finger is dipped in mercury, sensations of pressure are not felt in the portion of the finger below the mercury, but at the circle formed by the level of the mercury.

Tactile sensations can also be produced by pulling the skin. If the pull is exerted upon a very small area of the skin, for example upon an individual tactile point, the sensation produced is nearly like that produced by pressure. Only when a larger portion is stimulated can we differentiate between pull and pressure.

The organs for the tactile sensation are probably the nerve wreaths of the hair [Haarnervenkränze] and the corpuscles of Meissner, for the following reasons:

1. In the regions of the body covered with hair, a tactile point is found very near the exit of each hair. The hair serves as a tactile apparatus, forming a lever whose shorter arm is in contact with the sensory mechanism in the skin, while the longer arm receives the stimulus.

2. In those regions of the body not provided with hairs, the division of the skin into tactile points corresponds with the distribution of the Meissner corpuscles.

The number of tactile points varies in different parts of the skin. In the palm of the hand there are from 40 to 50 in 1 sq. cm.

The liminal intensity of the stimulus for the tactile sensation depends upon:

1. The place of stimulation. The lips, finger-tips, and forehead are the most sensitive. For the finger-tips the liminal intensity is 0.03 g acting upon 1 sq. mm. surface. The least sensitive portions are those covered with thick epidermis, for example the soles of the feet. 2. The extent of surface stimulated.

With increase of surface, the liminal intensity first decreases rapidly, then increases slowly.

3. The rapidity of the stimulus.

The liminal intensity is, to a certain extent, the smaller the more rapidly the pressure is exerted.

The ability to distinguish two unequal pressure stimuli of moderate intensity corresponds with the law of Weber (see page 256). The difference-threshold is about $\frac{1}{30}$ of the already acting weight, i.e. we can recognize the difference between two weights if they have the ratio of 29 : 30.

The law of Weber does not hold good for very small or very large weights.

The tactile sensations appear and disappear very rapidly. Even 460 shocks per second are still perceived as individual shocks.

(*b*) and (*c*) **The sensations of heat and cold.**—These sensations are produced either by increasing or decreasing the heat conveyed to the skin while the loss of heat remains constant, or by increasing or decreasing the loss of heat by the skin while the heat conveyed to it remains the same. The last is the case, e.g., in applying warm or cold objects to the skin. Sensations of temperature are produced chiefly by changes in the temperature of the skin, to a less extent by constant high or low temperature.

Under certain circumstances a paradoxical sensation of cold can be produced by the application of a warm body to a cold point.

The detection of differences in temperature is most delicate when the objects coming in contact with the skin have a temperature between 27° and 33°. Between these temperatures we are able to perceive a difference in temperature of $\frac{1}{20}$° C. For the higher and lower temperatures the detection of differences is less accurate.

The end-bulbs of Krause are probably the organs for the sensation of cold; the so-called genital corpuscles, for sensation of heat.

(*d*) **Sensation of pain.**—The pain points can be stimulated by a great number of stimuli. The intensity of pressure and temperature stimuli in order to produce a sensation of pain must be greater than that necessary to produce sensations of touch and temperature.

The sense organs for pain are probably the free nerve endings in the epidermis. In the central part of the cornea, where only pain points are present, only free nerve endings are found.

The sensation of pain appears and disappears more slowly than tactile and temperature sensations. When the stimulus is of short duration, it can be noticed that the sensation of pain is preceded by a sensation of touch or temperature. When more than 20 stimuli per second are received, we can no longer distinguish individual stimuli.

3. **The localization of sensation in the skin. Sense of locality.**—The sensations produced by stimulation of the skin are associated with conceptions of definite areas of the skin. By this we are able to locate the place stimulated.

The measure of this power of localization is the distance that two parts of the skin must be separated in order that by their stimulation two distinct sensations shall result. The power of localization has thus far been determined chiefly for the tactile sensation.

The distance which these two points must be separated depends on the manner of stimulation, that is, whether the points are stimulated simultaneously or successively. If stimulated simultaneously, the distances for various parts of the body are as follows:

Tip of tongue	1 mm
Tip of finger	2 "
Lips	4.5 "
Forehead	22 "
Back of hand	31 "
Upper arm and thigh	68 "

When the points are stimulated successively the distances are much smaller, being equal to the distances which separate the individual tactile points. For successive stimulation, therefore, each tactile point has a special space value.

An area of the skin in which two stimuli cannot be distinctly felt is called a *tactile area*. The tactile areas for successive stimulation are smaller than those for simultaneous stimulation.

CHAPTER XXVI

ORGAN SENSATIONS

THE organ sensations are produced by the stimulations of sensory nerves of an organ by the internal processes taking place in that organ.

They may be classified as follows:

1. Sensations of pain may proceed from all organs of the body. The quality of these sensations is the same as that of the pain sensations from the skin. But the power of localizing the pain in the organ is very imperfect.

2. The sensation of muscle tension. This enables us to estimate the weight of a raised body. The muscular sense is measured by determining the accuracy with which the weight of a raised body is estimated.

These sensations are produced by the stimulation of the sensory nerves not only in the muscles, but also in the tendons. In fact the nerves of the tendons seem to be of greater importance for the sensations of tension than those of the muscles. But the nerves of the muscles sooner call forth sensations of the degree of muscular activity (fatigue sensation).

3. The position of the limbs of the body is probably perceived by the sensibility of the joints, which may be regarded as closely related to the tactile sensation of the skin.

The sensibility of muscles, tendons, and joints serves in judging the position and movements of the body.

Centripetal fibres from the muscles, tendons, and joints also call forth reflexly coördinated movements for the maintenance of the equilibrium of the body. If the centripetal parts are diseased, as in locomotor ataxia (see page 229), disturbances in the movements occur.

It is supposed by many authors that muscular sensations are due to the fact that we are conscious of the degree of innervation of the motor nerve in the central organs.

There are still a number of organ sensations which are of such an indefinite character that at present little can, with certainty, be said about them. The knowledge concerning them is diminished by the fact that they are often accompanied by strong feelings (bonheur and ennui) by which their quality is masked. They are generally called *common sensations* and include hunger, thirst, itching, tickling, shuddering, fatigue, pleasure, ennui, giddiness, etc.

Of special physiological interest are the organ sensations, hunger and thirst, as they call for the partaking of solid and liquid food. The *sensation of hunger* is the sensation of an empty alimentary canal, which disappears even when the stomach is filled with an undigestible substance. In the sensation of hunger the sensory nerves of the stomach and intestine seem to play a part. If the period of hunger is long continued, an undefinable sensation of general need of food is present.

Thirst is the sensation produced by dryness of the pharynx, which disappears when the mucous membrane of the palate and the pharynx is moistened. Hence the sensation of thirst is produced by the stimulation of the sensory nerve of the mucous membrane by drying.

PART III

REPRODUCTION AND DEVELOPMENT

CHAPTER XXVII

REPRODUCTION

The first living beings must have originated by **spontaneous generation** (generatio æquivoca), i.e. the origination of living beings from lifeless material. At present, spontaneous generation, so far as we know, does not occur, and new living beings originate by **biogenesis,** i.e. the formation of living beings from separated parts of previously existing living beings.

Reproduction may be :

(*a*) **Non-sexual** (reproduction by fission, budding, spore formation). In this, one separated portion of a living being develops into a new individual.

(*b*) **Sexual** reproduction, in which two sexually different cells (egg and sperm cell) unite and develop into a new living being. These two sexual cells may either originate from one individual or from two sexually different individuals (male and female).

Human beings are propagated by sexual reproduction in which the egg-cell provided by the female unites with the sperm-cell furnished by the male and from this a new individual develops.

1. THE MALE SEX-PRODUCTS AND THEIR FORMATION

1. **Composition of the seminal fluid.**—The seminal fluid is a viscid, whitish, turbid fluid having a peculiar odor and a neutral or alkaline reaction in which are suspended the

solid elements, the spermatozoa. The seminal fluid contains 18% solids which include chiefly proteids, as also lecithin, cholesterin, fats, salts, and spermin (Diethylen diamine). Spermin, having a constitution of  $C_2H_4\left\langle {NH \atop NH} \right\rangle C_2H_4$, is a base and is present in the fluid as the salt of phosphoric acid and by evaporation of the fluid is precipitated as crystals. The spermatozoa contain the ordinary constituents of nucleated cells, i.e. proteid, nucleo-albumin, nuclein, nuclein bases, potassium phosphate.

The spermatic filaments or **spermatozoa** are cells with pear- or oval-shaped heads and the attached rod-shaped middle piece which passes over into the threadlike tail. The length of the whole spermatozoon is 0.05 mm. The cells are poor in proteids, the head being the nucleus, and the middle piece and the tail the protoplasm.

The spermatozoon moves about by the whiplike movements of the tail and, during its movements, rotates about its long axis. The movements of the spermatozoon are most lively immediately after the ejection of the seminal fluid. It is favored by weak alkali reaction. Strong alkalies and also acid reactions inhibit the movements. In the genital canals of the female the spermatozoa retain their movements for a very long time.

2. **Formation of the spermatozoa.**—The formation of the spermatozoa takes place in the convoluted tubules of the testis. Certain cells of the walls of these canals change to the spermatoblasts which grow out into the canal. By cell division and the separation of the newly built cells the spermatoblast forms the spermatozoon. In this the nucleus forms the head, while the protoplasm forms the middle piece and tail. Concerning details of the morphological changes in this process the results of investigators are contradictory. In the testis there is formed simultaneously, in some unknown way, the fluid in which the spermatozoa are suspended. The formation of spermatozoa in the testis takes place, no doubt, continuously. The seminal fluid is passed into the

vasa deferentia, where it is stored up. During the ejaculation, it is mixed with the secretion of the vesiculæ seminales, the prostate, and Cowper's glands. Very little is known concerning the secretions of these glands or the nature and importance of their secretions. The prostate is supposed to secrete the spermin and odoriferous substance found in the mixed seminal fluid.

3. **Discharge of the seminal fluid. Ejaculation.**—The discharge of the seminal fluid takes place during erection by the activity of certain muscles by which the fluid is forced out of the vasa deferentia and the urethra.

(*a*) **Erection.**—During erection the blood vessels of the penis are well filled. This filling of the penis is brought about by

(1) Increase of blood carried to it by the dilation of the arteries. The dilation is produced by the vaso-dilator nerves, the nervi erigentes (see page 77).

(2) The removal of the blood is prevented by the compression of the venæ profundæ penis. The compression of these veins is produced by the contraction of the musculus transversus perinei.

The centre by which the erection is brought about is situated in the lumbar cord. It can be stimulated either reflexly by the stimulation of the sensory nerves of the penis or by impulses from the cerebral hemispheres (psychical).

(*b*) **Ejaculation.**—The ejaculation is accomplished by the peristaltic contractions of the muscles of the vasa deferentia and vesiculæ seminales which drive the fluid into the urethra and thence it is propelled forward by the contraction of the bulbo- and ischio-cavernosus muscles. The passage of the urinary bladder is cut off by the erection of the caput gallinaginis. The act of ejaculation can be called forth reflexly by stimulating the sensory nerves of the penis. The centre of ejaculation lies in the lumbar cord.

The amount of seminal fluid discharged during one ejaculation is 1–6 cc.

2. THE FEMALE SEXUAL PRODUCTS AND THEIR FORMATION

1. **The ovum.**—The female sexual cell or egg is a spherical cell having a diameter of 0.15–0.2 mm. Its protoplasm is called egg-yolk; its nucleus, germinal vesicle. It is surrounded by the zona pellucida. In the yolk we can distinguish:

(1) The real living substance, the *protoplasm*.

(2) The *deutoplasm*, or yolk granules, which serves as food.

In the human ovum there is but little deutoplasm in the form of spheres, yolk granules, lying in the protoplasm. In many animals, e.g. birds, much deutoplasm is present. The nucleus of the egg is generally spherical, clear, and with a double contour; it surrounds the germinal spot (macula germinativa). The zona pellucida is 0.02–0.025 mm thick and radially striated. These striations are caused by the numerous perforations of the zona pellucida.

2. **Formation of the ovum.**—The eggs in the ovary are placed in the Graafian follicle, a spherical vesicle, which in mature condition has a diameter of 10–15 mm. The follicles are imbedded in the connective-tissue stroma of the ovary and are surrounded by a vascular capsule. The inner wall of this capsule is surrounded by the membrana granulosa or germinativa, composed of many layers of epithelial cells. The epithelium forms at one place a great mass of cells, called the discus proligerus, in which lies the ovum. The cavity of the follicle between the discus proligerus and the rest of the wall of the follicle is filled with a yellowish fluid containing proteid.

The Graafian follicle originates as follows: The surface of the ovary is covered with a cylindrical epithelium (the so-called germinal epithelium) which covers also the tubular invagination of the surface of the ovary. These invaginations grow downward and are cut off by the stroma of the ovary. The separated tubes develop into the Graafian follicles. In the germinal epithelium the round egg-cells are already present and grow downward with the epithelium of the tube. The first appearance of the follicle, that is, the formation of the primordial egg, occurs in the embryo. At first the follicles are only 0.03 mm in diameter. When fully developed they pass through the deep layers of the stroma to the surface of the ovary.

3. **Ovulation or discharge of the ovum.**—The discharge of the egg takes place by the bursting of the ripe Graafian follicle. This bursting is accomplished by the increase of liquid in the follicle whereby it is enlarged and its walls are rendered tense until they burst.

In the place formerly occupied by the follicle a cicatrix is formed which is colored yellow by pigments: corpus luteum.

The contents of the follicle, including the egg, lying among the cells of the discus proligerus, reaches the end of the oviduct, whose fimbriated end lies close to the surface of the ovary. By the ciliated epithelium the egg is carried through the oviduct to the uterus.

In human females the discharge of the egg occurs regularly every four weeks. It is accompanied by a capillary bleeding from the mucous membrane of the uterus—menstruation, lasting from two to three days. The hemorrhage is preceded by a separation of the mucous membrane and the formation of a membrane, the decidua menstrualis, which is afterward cast out. During menstruation 100–200 g blood are lost.

4. **The maturation of the egg.**—Previous to fertilization certain changes take place in the egg which are collectively called the maturation of the egg. The nucleus of the egg moves towards the periphery and divides by indirect division into two nuclei. One of these, called the polar body, is cast out of the egg. The other nucleus again divides into two, one of which, the second polar body, is also cast out. The remaining nucleus, called the female pronucleus, travels to the centre of the egg.

3. FERTILIZATION

The spermatozoa discharged during the act of coition into the vagina of the female pass through the uterus and oviduct into the upper part of the oviduct, called the ampullæ. This is an active movement and takes place in the direction opposite to that of the movement of the cilia of the epithelium.

After discharge of the egg fertilization takes place, generally in the ampulla, by the entrance of one of the spermatozoa into the egg. The spermatozoon forces its way through the membrane of the egg and proceeds in a radial direction towards its centre. The tail of the spermatozoon becomes dissolved in the egg, while the head becomes the male pronucleus. The male and female pronuclei increase in size and approach each other. They are now similar in appearance, so that they can no longer be distinguished.

After losing the nuclear membrane the nuclear fibres of each nucleus break up into a number of loop-shaped pieces, and these fragments are mixed. From the thus united egg and spermatozoon the new individual develops by nucleus- and cell-division and cell differentiation.

While the unfertilized eggs are soon destroyed, the fertilized egg, passing in about three days through the duct into the uterus, is held in the uterus. It sinks between the folds of the mucous membrane of the uterus, which is greatly thickened. The walls of the fold unite with the membrane of the egg and cover the egg. This part of the mucous membrane subsequently forms the placenta.

CHAPTER XXVIII

PHYSIOLOGY OF THE EMBRYO

1. SYNOPSIS OF SOME OF THE IMPORTANT FACTS OF EMBRYONIC DEVELOPMENT

By the **process of fertilization** the fertilized egg-cell divides into many cells which form a one-cell layer below the egg membrane, which takes no part in this cell division. By this a cavity filled with fluid, the segmentation cavity, is formed in the centre of the egg. The structure thus formed is called a **blastula,** and the one-celled layer is called the **ectoderm.** The blastula expands by the continual increase of fluid in the segmentation cavity. Below the ectoderm a second layer of cells, the **endoderm,** is formed. The manner in which the endoderm is formed varies in different animals. Finally, at a thickened portion of the blastula, a third layer, the **mesoderm,** is formed between the ectoderm and the endoderm. From the ectoderm originate the epithelial cells of the skin and its glands, the nervous system, the epithelium of the sense organs, and the lens. From the endoderm are formed the epithelial cells of the alimentary canal and its glands and those of the urinary tubes. From the mesoderm originate the blood and blood vessels, the muscles, connective tissue, and the reproductive cells.

The thickening of the walls of the blastula at which the mesoderm originates is called the **germinal disk** ; in this the first traces of the embryo are seen. The germinal disk assumes a biscuit form, its borders curving inward and thereby separating that part of the cavity of the blastula

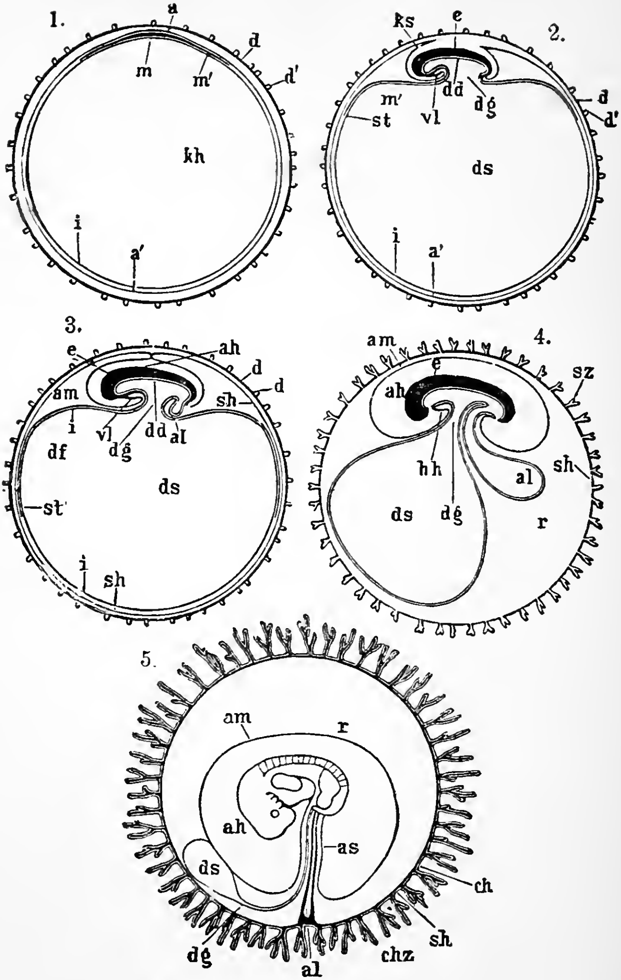

Fig. 49.—Development of the Fœtal Membranes of a Mammal. (After Kölliker.)

1, ovum with zona pellucida, blastula, and embryonic area; 2, formation of yolk-sac and amnion; 3, union of the folds of the amnion, forming the amniotic cavity; formation of the allantois; 4, decrease of the yolk-sac, increase of the allantois, formation of mouth and anus; 5, reduction of the yolk-sac; allantois joined to the chorion, enlargement of the amniotic cavity; *d*, zona pellucida; *d'*, processes (villi) of zona; *sh*, serous membrane; *sz*, villi; *ch*, chorion. *chz*, chorionic villi; *am*, amnion; *ks*, head-fold of amnion; *ah*, amniotic cavity; *as*, navel-cord with the amnion; *aa'*, ectoderm; *i*, endoderm; *mm'*, mesoderm; *dd*, embryonic part of the endoderm; *df*, area vasculosa; *st*, sinus terminalis; *kh*, cavity of the blastula; *ds*, umbilical vesicle (yolk-sac); *dg*, passage of the umbilical vesicle; *al*, allantois; *e*, embryo; *r*, space between chorion and amnion; *vl*, ventral body wall; *hh*, pericardial cavity.

lying below the germinal disk, i.e. the *embryonic intestine*, from the part above, i.e. the *yolk-sac*. The connection between these two cavities, as long as it is open, is called the vitelline duct (see Fig. 49).

The ectoderm forms a fold over the curved germinal disk. The inner leaf of this fold grows over the embryo and forms, by separating from the blastula, the **amnion,** which at the navel passes over into the skin of the embryo. The outer leaf of the fold joins the zona pellucida and forms with it the serous membrane, which later on is called the **chorion.** On the surface of the chorion villus-like processes are formed which unite with the mucous membrane of the uterus. From the posterior part of the embryonic intestinal cavity a tubular projection, the **allantois** or the urinary sac, grows out into the space between the yolk-sac and the chorion. Its inner part (lying in the embryo) becomes the urinary bladder. The allantois grows outward until, in the third week, it joins the chorion and forms with it the **placenta.** The lumen of the allantois soon disappears and forms a cord composed of mucous tissue and is called the umbilical cord.

Chronology of the development of the embryo.

First month.

First week. Passage of the egg through the tube; fertilization; formation of the blastula.

Second week. Blastula attains a diameter of 5 mm; villus-like processes formed on the egg membrane; first rudiments of embryo; formation of the spinal folds and of the medullary groove.

Third week. Embryo about 4 mm long. Formation of the amnion, yolk-sac, and allantois. The yolk-sac circulation is established.

Fourth week. Embryo from 8 to 11 mm long. The position of the extremities is clearly visible. The three cerebral vesicles are present.

Second month. Length of embryo 30 mm. The yolk-sac circulation degenerates, while the placental circulation develops. Formation of the face; disappearance of the gill-clefts and posterior gill arches; the extremities become jointed; first points of ossification in the hip-bone and lower jaw; abdominal cavity closed; kidneys formed.

Third month. Length of embryo 70 mm. Commencement of sexual differentiation.

Fourth month. Length of fœtus 17 cm, weight 100 g. It is possible to distinguish male and female organs from each other. Placenta weighs 80 g. First movements of the extremities. Meconium in intestine.

Fifth month. Length of fœtus 30 cm, weight 280 g. Hair on the head and body [lanigo] appear. Beginning of sebaceous secretions. Placenta weighs 178 g.

Sixth month. Length of fœtus 34 cm, weight 700 g. The fat layers of the skin develop. Movement of the embryo. Born during this month the child makes feeble respiratory movements but is not viable.

Seventh month. Length of fœtus 38 cm, weight 1300 g. Born during this month the child whines and is sometimes viable.

Eighth month. Length of fœtus 42 cm, weight 1570 g. Testicles descend. Child is viable.

Ninth month. Length of fœtus 65 cm, weight 1970 g.

The mature embryo is 50 cm long, weighs 3 kg.

2. METABOLISM OF THE EMBRYO

(*a*) **Circulation.**—In explaining the embryonic circulation two periods must be kept distinct: (1) the period of vitelline [yolk-sac] circulation; (2) period of the placental circulation.

(1) **Vitelline circulation.**—The first formation of vessels occurs near the germinal disk. From the cells of the mesoderm originate the peripheral veins (sinus terminalis) from which spring the blood vessels of the embryo. From the wall of the vein solid cords of cells extend into the embryo which anastomose and become hollow by the formation of intercellular spaces filled with an intercellular fluid. The heart is formed from two symmetrical vessels in the alimentary canal in the head which represent the primitive aortæ. These coalesce in the median line, forming a tube. From this tube the heart is developed by the formation of an S-like curve, whereby the tube is divided into an auricle, ventricle, and truncus arteriosus. By a partition appearing in the tube, the right and left heart are formed. From the heart there spring originally two aortic arches which give off the omphalo-mesenteric arteries. The branches of these arteries pass through the germinal disk to the sinus ter-

minalis, while veins proceed from the sinus to the heart. The system of vessels thus formed is called the vascular area. Shortly after the heart is formed it begins to beat rhythmically, thereby setting in circulation the fluid formed in the vascular system. It is worthy of note that the cardiac muscle contracts rhythmically at a time when it contains no ganglionic cells.

By means of the vitelline circulation the embryo is supplied with nourishment which has been taken up by the blood from the yolk-sac.

The red blood corpuscles originate from the so-called blood islands, i.e. groups of cells in the cords from which the blood vessels are developed. The cells of the blood islands form blood pigment, separate, and then appear as nucleated blood corpuscles suspended in the fluid.

(2) **Placental circulation.**—From the abdominal aorta formed by the union of the primitive aortic arches proceed the two umbilical arteries through the umbilical cord (the wall of the allantois) to the place where the allantois joins the chorion and where the placenta originates. Here the arteries split up into capillaries. From these capillaries the blood is collected by the umbilical vein, which passes through the umbilical cord to the navel; thence, as the ductus venosus Arantii, under the liver to the inferior vena cava.

At this time the right and the left heart are not yet completely separated. In the septum between the auricles exists an aperture, the *valvula Eustachii.* The pulmonary arteries and the aorta are still united by one of the primitive aortic arches,* the so-called *ductus Botalli.* Part of the blood from the right auricle passes, therefore, through the valvula Eustachii directly into the left auricle and thence into the left ventricle and aorta, while part of it passes from the right

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* Corresponding to the five pairs of gill-arches, five pairs of aortic arches are formed which undergo the following changes: The first two pairs disappear; the third pair forms the external carotids; the fourth arch on the left side forms the aorta, on the right side, the right subclavian; the fifth on the left side, the ductus Botalli and the left pulmonary artery; on the right side the right pulmonary artery.

auricle into the right ventricle and pulmonary artery and thence directly through the ductus Botalli into the aorta. Only a small part of the blood pases through the lungs of the embryo. This peculiar arrangement of the blood vessels becomes clear when we recollect that the exchange of gases in the embryo does not take place in the lungs and that consequently only so much blood needs to flow through the lungs as is sufficient to provide for their nourishment and growth. After birth, when pulmonary respiration begins, the division between the auricles of the heart is completed and the ductus Botalli is obliterated.

The **placenta** is a very vascular structure, composed of two united parts, one part the maternal, the other the fœtal, portion. The vascular villi of the fœtal portion extend into spacious blood cavities formed by the dilated capillaries of the maternal portion. This great abundance of vessels in the placenta, part of which belong to the fœtus and part to the mother, makes a rapid exchange of gases between the maternal and the fœtal blood possible.

The formation of red blood corpuscles during the placental circulation takes place chiefly in the liver and spleen of the embryo.

During the middle of pregnancy the **cardiac sounds** of the embryo can be heard at different parts of the uterus according to the position of the embryo. The double sound is often accompanied by noises caused by the circulation of blood in the umbilical cord. The rate of the cardiac sounds of the embryo is 120–160 in a minute. It is increased by movements of the embryo.

(*b*) **Respiration.**—In regard to the respiration of the embryo, two periods can be distinguished. During the first period corresponding to the vitelline circulation the supplying of oxygen and removal of carbon dioxide is not brought about by any special organs. Real respiration begins with placental circulation. The taking up of oxygen and giving off of carbon dioxide does not take place in the lungs but in the placenta. The oxygen is supplied by the arterial blood of the mother, and the carbon dioxide of the embryo is taken up by it.

Metabolism and the corresponding need of oxygen in the embryo is small. The exchange of gases in the placenta is sufficient to maintain the embryo in apnœa. But this condition ceases immediately when, by compression of the umbilical cord or by premature rupture of the placenta, the normal exchange of gases in the blood of the embryo is stopped. The blood of the embryo then lacks oxygen, while the carbon dioxide accumulates by which the respiratory centre is stimulated and premature respiratory movements are made.

The lungs of the embryo are developed from two diverticuli of the ventral wall of the esophagus and contain no air (atelectatic); the alveoli are formed, but are collapsed, i.e. filled by cuboidal epithelial cells. No negative pressure exists in the pleural cavity. When by the first inspiratory movement after birth air is forced in, the epithelial cells of the alveoli are flattened, the alveoli contain air, and, after some time, negative pressure is developed in the pleural cavity. As to the origin of this negative pressure authors do not agree.

(*c*) **Nutrition of the embryo.**—All the nourishment which the embryo needs for its metabolism and growth is derived from the mother organism. In regard to nutrition we can distinguish two periods, one of which corresponds to the vitelline circulation, the other to placental circulation. During the first period the embryo is supplied with food by the blood of the yolk-sac. The food transudes from the vessels of the mucous membrane of the uterus through the mucosa and egg membranes to the yolk-sac. During the placental circulation, however, the embryo takes its food from the blood of the mother present in the placenta. The food transudes from the maternal vessels of the placenta into the fœtal placental vessels. As the yolk-sac is of no further importance after the completion of the placental circulation, it gradually diminishes in size and finally dwindles away almost entirely, what is left being called the umbilical vesicle.

(*d*) **Secretions of the embryo.**

1. **Meconium.**—Meconium is a dark brownish-green mass having the consistency of pitch. It is found in the intestine of the embryo, from which it is discharged soon after birth. It contains 20–28% solids, which include mucin, bile acids, bile pigments (bilirubin and biliverdin, but no hydrobilirubin), cholesterin, fats, soaps. Substances in the fæces of the adult which indicate intestinal putrefaction are lacking in meconium. Meconium may be regarded as a solidified secretion of the glands of the intestines, and its composition indicates that the liver is the chief seat of its formation.

The liver is formed early by diverticuli of the intestinal wall in the form of the primitive liver ducts, which, by branching, form the smaller bile passages. The liver secretions take place as early as the third month.

2. **Formation of amniotic fluid.**—The amniotic fluid is found in the amniotic cavity and surrounds the embryo. It has a weak alkaline reaction; its specific gravity varies considerably, 1.002–1.028. It contains some proteids, salts, urea, allantoin, and kreatinin. The amniotic fluid is formed not only by the embryo, but also by the mother organism. That part of this fluid is derived from the mother organism is proved by the fact that sodium sulphindigotate injected into the mother organism is found in the amniotic fluid, but not in the embryo. Still the amniotic fluid is partly an excretion product of the embryo, the urine of the embryo being discharged into the amniotic cavity.

In the development of the urinary organs, the pronephros, or Wolffian bodies, are first formed. These are glandular organs lying on either side of the vertebral column. They are composed of coiled uriniferous tubules which carry, at their closed end, a glomerulus and at the other end, open into a common duct, the Wolffian duct. This duct opens into the cloaca, whose anterior end forms the urethra by the formation of the perineum. Later on the permanent kidneys are formed by the diverticuli of the posterior end of the Wolffian duct. These diverticuli branch and the branches become the uriniferous tubules of the kidneys; at their closed ends a glomerulus forms. In the female the Wolffian duct is obliterated, while in the male it forms the vas deferens.

3. The sebaceous secretion begins in the fifth month. The substance thus secreted forms a fatty layer upon the skin and is called the vernix caseosa.

The removal of metabolic waste products from the embryo is accomplished not only by the glands (liver and kidneys), but also by the exchange of gases between the fœtal and the maternal blood in the placenta.

(*c*) **Metabolism.**—The metabolism of the embryo is small; little heat needs to be produced, for the loss of heat is exceedingly small. The muscular movements which could increase metabolism are very limited. Hence the food supplied to the embryo is chiefly used for its growth.

3. THE TRANSFORMATION AND SETTING FREE OF ENERGY IN THE EMBRYO

(*a*) **Muscular movements.**—The first appearance of the skeletal muscle is during the second month of pregnancy.

Muscular movements, excepting the beat of the heart, begin at the fifth or sixth month. They consist of jerky movements of the limbs against the walls of the uterus. The movements of the fœtus appear to be reflex movements; they are increased when the fœtus is pushed by pressing upon the abdominal walls of the mother. At the close of pregnancy, weak rhythmic respiratory movements are sometimes made, also movements of sucking and deglutition; swallowed amniotic fluid may be found in the embryo.

(*b*) **The development of the functions of the nervous system.**—The researches concerning the medullation of the nerves furnish the basis for judging the development of these functions. The nerve fibres at first have no medullary sheath, but acquire this structure later on, and nerve fibres of different functions acquire it at different periods. The development of the medullary sheath can be readily investigated, for the medullated nerve fibres are white, while the fibres not containing this sheath appear gray. It may be assumed that the function of the nerve fibre is only completely present when the nerve sheath has been formed.

In the *spinal cord* the medullary sheaths of the anterior and posterior roots are first formed, i.e. the tracts serving for reflex actions. After this, the sheaths of the antero-ground, the lateral ground bundle, and of Burdach's column, i.e. bundles which contain fibres chiefly for the indirect reflex tracts. Then the sheaths of the long sensory tracts leading to the brain are formed, and finally the sheath of the long motor tracts leading from the brain. From the successive developments of the medullary sheaths it is evident that, in the spinal cord, the simpler reflexes appear first; next the more complicated and radiated; and finally the paths for the stimuli causing sensations and voluntary movements.

In the corona radiata, the centripetal fibres for the sensory areas of the *cerebral cortex* are developed before the corresponding centrifugal fibres; hence the conditions for the formation of sensations are perfected before those for the formation of voluntary movements. Some of the fibres for the sensory areas develop after birth (see page 329).

In the *medulla oblongata*, however, there appear at an early date groups of cells whose axis-cylinder processes course down the anterior and lateral columns of the cord (hence centrifugal fibres); these fibres are already medullated when the sensory roots of the medulla have no medullary sheaths. These cells and fibres are, therefore, well developed and function at the time when the posterior roots still appear embryonic. This indicates that the action of centres is automatic and not reflex. The sensory nerves, when fully developed, stimulate and eventually regulate the centres which, prior to this, were already active. It must be remembered that the medulla contains the important nerve centres which maintain the vegetative functions of the body.

Little need to be said concerning the physiological development of the sense organs. The only sensations which can come into account in the fœtal life are the tactile, pain, and, perhaps, some organ sensations. These evidently call forth the movements of the fœtus.

4. DIFFERENTIATION OF SEXES

The reproductive organs are developed as follows: On the ventral side of the pronephros, the genital ridge and a special duct, Müller's duct, running parallel with the Wolffian duct and also opening into the cloaca, are formed. In the male the genital ridge forms the testis, the pronephros forms the hydatid of the epididymus, the Wolffian ducts the vas deferens; the duct of Müller is obliterated except a small rudiment, called the uterus masculinus. In the female the genital ridge becomes the ovary, Müller's duct the oviduct; and the mouth of the Müller's duct at the cloaca dilates and forms the uterus. The Wolffian duct disappears. Nothing is known concerning the causes of sexual differentiation.

CHAPTER XXIX

PREGNANCY. PARTURITION. CHILDBED

During the development of the fœtus in the uterus, the following changes occur in the maternal organism: The muscle fibres of the uterus increase in size and number and the whole uterus increases enormously. In the virgin state the uterus is 7 cm long, 3.2 cm broad, and weighs 30 g; at the end of pregnancy it is 37 cm long, 26 cm wide, and weighs about 1 kg. The intramuscular connective tissue loosens and increases and the blood vessels, nerves, and lymph vessels also increase. The mucous membrane of the uterus thickens and grows over and covers the egg, forming the decidua. That part of the wall of the uterus which grows over the egg is called the decidua reflexa, while the part bordering upon this is called the decidua vera. The placental part of the decidua vera is called the decidua serotina. As the uterus increases it fills the pelvic cavity and forces the intestines aside and the diaphragm upward. During pregnancy ovulation and menstruation cease.

The breasts begin to increase in size during the first months of gestation, the nipple and the areola assume a dark color, the milk glands yield spontaneously or upon pressing a light-colored watery fluid.

Metabolism is increased during pregnancy.

The period of gestation reckoned from the day of the last menstruation is about 270–280 days.

Parturition is effected by the contraction of the muscles of the uterus by which pressure is exerted upon the contents of the uterus. The pressure thus produced may be as much as 100 mm Hg. By these contractions the fœtus is pressed against the cervical canal, which dilates and stretches so that the uterus and the vagina form a common tube. The membrane of the egg (the decidua reflexa of the utrinal mucous membrane, the chorion and the amnion) are ruptured so that the amniotic fluid is discharged. By further contraction of the uterus the child is forced through the vagina and pelvis, generally head-foremost. Parturition is aided by compression of the abdomen. Soon after the birth of the child the placenta is loosened by the further contraction of the walls of the uterus and, under loss of some blood, is discharged with the egg membranes (after birth).

The innervation of the uterus takes place by means of the nerves from the lowest thoracic and from the lumbar cord. A part of the fibres pass through the sympathetic, while another part pass directly with the sacral nerves to the uterus. The centre for the contraction of the uterus lies in the lumbar cord. This centre can be stimulated reflexly by stimulations from the centripetal nerves of the uterus. These centripetal nerves are stimulated by the tension in the walls of the uterus caused by the growing fœtus. In dogs in which the lumbar cord is separated from the rest of the nervous system, normal parturition can still take place.

The duration of parturition varies. In case of the first-born it may last 20 hours, but in subsequent cases it is shorter. During parturition the contractions of the uterus gradually become more intense, frequent, and longer until the child is expelled. These contractions are accompanied by pain. During each "pain" the temperature, rate of pulse, and perspiration are increased.

After parturition the uterus assumes its normal form, many of the muscle cells undergoing fatty degeneration. The inner surface of the uterus acquires a new epithelial lining, and after about four weeks the regeneration of the mucous membrane is complete. As long as a mucous membrane is not regenerated, it behaves like a wound and secretes a corresponding wound secretion. This secretion which is cast out is called *lochia.* The lochia is bloody during the first days, during the fifth day it is serous, later on it becomes grayish.

The breasts swell much during the second and third days after parturition. The first secretion—colostrum—is a thick, yellowish fluid, containing colostrum corpuscles (see page 112); at the third day real milk is secreted. The period of lactation lasts about ten months, and during this time menstruation does not take place.

CHAPTER XXX

DEVELOPMENT OF THE BODY AFTER BIRTH

1. INFANCY

DURING infancy the body is nourished by fluids only, chiefly by milk. As the formation of the first teeth is connected with the ability to take up solid food, the period of infancy extends from birth till the first dentition.

(*a*) **Circulation and respiration of the infant.**—Immediately after birth the circulation in the umbilical vessels ceases, and the umbilical cord constricts. If it is then cut, no bleeding, as a rule, results, yet to prevent possible bleeding it is ligatured and cut. Animals cut the umbilical cord with their teeth. The part of the umbilical cord left attached to the child dries up and falls off after a few days. The navel discharges matter for some time and heals after 12–14 days.

Immediately after birth the first inspiration is made. The alveoli of the lungs fill with air and their epithelial cells become flattened. Simultaneously the blood streams more abundantly through the vessels of the lungs. Gradually the ductus arteriosus Botalli is obliterated and the septum between the auricles is completed. The remains of the umbilical arteries and veins degenerate to connective tissue.

The rate of the pulse during the first week is 120–140 per minute; during the second year 110. The number of respirations in the new-born is 44 per minute; during the third year 35–40.

(*b*) **Nutrition and growth of the infant.**—The normal nourishment for the infant is the milk of the mother. The replacement of this by other food (e.g. cow-milk or artificial preparation) must be regarded as makeshifts and are often not suited for the child. The average amount of milk which the infant takes is as follows: During first day 30 grams, second day 150, third day 400, fourth day 550 grams; after one month 650, three months 750, four months 850, six to nine months 950 grams.

The length of the body of the child at birth is about 50 cm.

The infant grows during the first month 4 cm, during the second month 3 cm, during the third month 2 cm, and during the following months 1–1.5 cm. The total increase in length during the first year is about 20 cm, during the second year 9 cm, and during the third year 7 cm. The weight after birth is 3 kg. Immediately after birth the infant loses from 100–300 grams of its body weight. After this its weight increases and after the tenth day it has regained its previous weight. During the first five months the weight of the normally nourished child increases on the average 20 to 30 grams daily; during the next seven months 10–15 grams daily. After one year the child weighs about 9 kg.

During the first days after birth the child discharges the meconium through the anus. Later on the stools of the normally fed child are yellowish and of medium consistency.

(*c*) **The nervous system and the senses of the infant.**—Concerning the physiological development of the central nervous system during infancy the following may be said: At birth certain reflex and coördinated movements, those necessary for the maintenance of life (respiration movements, sucking, deglutition) are present. Sucking takes place reflexly when a foreign body touches the lips. The coördinated movements which play a part in standing and walking are not present in the human infant immediately after birth, but are learned during the first or second year. This is also true for the coördinated movements for speech. The reflex irritability is greater in the infant than in the adult. Reflex cramps can be produced by relatively feeble stimulation of sensory nerves (e.g. convulsions during dentition, tetanus).

At birth the conducting fibres for the sensory areas of the cerebral cortex are not all medullated. The tracts for the visual centre develop their sheaths at the time of birth, while those of the auditory area are developed after birth. The fibres of association develop about three months after birth.

As to the development of the senses the following facts may be stated in regard to sight. During the fifth week, fixation, associated movements of the eyes, closure of the eyelids when the macula lutea is illuminated, and accommodation take place. Only during the fifth month is there a development of orientation of the visual field and closure of the eyelids when the periphery of the retina is illuminated. Until the fifth month the eccentric visual sensations are not utilized. The child, therefore, appears as if it had an extremely limited visual field. An object upon which the gaze is fastened is, during the fifth month, followed by the eyes, but moving objects upon which the gaze is not fixed do not call forth, during the first period, fixation of the eye. At first the infant does not see the objects as solid objects and it lacks all judgment of size and distance. (The child reaches, e.g., for the moon.) It is also asserted that at birth the sense of color is absent, and that this begins to develop during the sixteenth month and is completely developed in the fifth or sixth year. The color sensations are first developed at the centre and later on at the periphery of the retina.

The other senses function immediately after birth, but it is said that the sense of hearing is then incompletely developed; this corresponds to the imperfect development of the tracts of the auditory centre in the new-born.

The change from infancy to childhood is marked by the first dentition. The first teeth, the so-called milk-teeth, develop in the following order:

Between seventh and eighth month the lower central incisors.

Between eighth and tenth month the four upper incisors.

Between twelfth and fourteenth month the four small inner molars and the two lower outer incisors.

Between eighteenth and twentieth month the four canines.

Between twenty-fourth and thirty-fourth month the four smaller outer molars.

Between the age of 4½ and 5 years, the first four large permanent molars appear.

2. CHILDHOOD

Childhood extends from the first dentition to puberty. During this period the physiological functions are about the same as in the adult human being, except that metabolism is relatively greater than in the adult, as already explained (see page 118), and that the sexual functions are not present. The second dentition takes place during childhood. It begins during the seventh year and extends to the fifteenth year. The temporary teeth are replaced by the permanent set and four new large molars are added. Between the ages of eighteen and twenty-five, and sometimes still later, the last molars, the wisdom teeth, are finally developed.

The following table shows the changes in the length and weight of the body at different ages:

Age.	Man.		Woman.	
	Length. m.	Weight. kg.	Length m.	Weight. kg.
Birth	0.5	3	0.5	3
5 years	1.0	15	0.95	14
10 "	1.3	25	1.2	24
15 "	1.6	44	1.5	40
20 "	1.7	60	1.6	52
30 "	1.7	65	1.6	55
40 "	1.7	65	1.6	55
60 "	1.65	62	1.52	54
80 "	1.6	58	1.5	49

3. PUBERTY

Puberty is the period of sexual maturity, which begins at the age between fourteen and seventeen. It is characterized by many changes in the body. In the male the formation of spermatozoa and beard take place, the larynx develops more powerfully, and the voice changes. Sexual desires awaken. The manly character appears. In castrated children these phenomena are not observed. Female puberty, which occurs a little earlier than in the male, is accompanied by ovulation and menstruation, and the external sexual organs are covered with hair and the mammary glands develop.

4. OLD AGE, DEGENERATION, AND PHYSIOLOGICAL DEATH

The prime of life in man extends from the twenty-fifth to the forty-fifth year. After this degeneration sets in, the body weight and length decrease. Metabolism and the functions of the organs are reduced. In high old age a great debility of the organs, especially of the brain and heart, sets in, which finally results in physiological death or death by senile decay. In the female this degeneration begins with the climacteric, the cessation of ovulation and menstruation. The greatest old age in man may be over one hundred years. According to the mortuary statistics, the average length of human life in civilized countries is thirty years.

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